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FALB'S THEORY OF EARTHQUAKES.

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[Read March 1, 1889.]

It was with considerable reluctance that I agreed to submit a paper upon a subject whereof so much is yet conjecture.

Although various earthquake theories have been advanced, it has always been the case that the more we study and compare them, and attempt to adjust earthquakes to certain laws as to their frequency, force, duration, etc., the more the conviction is forced upon one, that they are the most lawless of natural phenomena. This will be all the more apparent to any one who attempts to study them in a region where they are comparatively rare, and very seldom of sufficient force to impress upon the observer their true character.

It is needless to say, that the proper place to observe them for theorizing is the region in or near the tropics, in the chain of the Andes in South America, for instance, where nature seems to have established her laboratory for manufacturing explosives on a grand scale. The individual features of such an event are there brought out with great prominence, and the frequent repetitions of those mighty earth tremors will soon impress upon one all their usual characteristics.

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We should be more likely, then, to give greater weight to observations taken for extended periods in the so-called earthquake regions of our globe, provided that the observer had been fully equipped with a thorough scientific knowledge of to-day, and endowed with a leaning toward original research.

Such an authority I have taken up in this paper, and what I shall state of earthquakes will be based upon the particular theory which he advances.

Although I have followed the subject with great interest for years, my individual information and collected data have been so meagre that I shall, at this time at least, leave it unconsidered, and devote myself entirely to the labors of a scientist by whose writings, notes and publications I have been guided.

"*Earthquakes are subterranean volcanic eruptions, caused by the cooling of the earth's interior, and aided by the attraction of the sun and moon.*"

With these words, Rudolph Falb, a German scientist of whom much has been said and written of late, summarizes a theory, which to develop he had spent long years of study, of laborious research, of toilsome travel and conscientious work.

When he made public the fundamental principles of his theory, he did not lack adversaries who attacked and held to ridicule his views, foemen worthy and unworthy of his lance; and though his enthusiasm for the subject may have made him too sanguine and often too positive in his assertions, there remain undeniable facts which command our consideration and thoughtful study. As time advances and more extensive researches are made, statistics will either help to strengthen or undo the fabric Falb has spun; and whatever may be said against his deduced laws, it is certain that science will never suffer by having such energetic weavers at its loom.

At first thought it strikes one as though there were really nothing particularly new about this theory, for, the cooling of our globe, the formation of a crust, the consequent contraction, the pressure of the outer shell upon the interior mass, the peculiar atomic condition of this mass, due to the immense and varying pressure, and the frequent disturbances interiorly, necessarily

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due to these causes, and to the infiltration of water into fissures —all these points had been brought out with most of our physical theories. The idea of a luni-solar influence upon the life of our planet, and its possible connection with terrestrial disturbances, had also suggested itself to physicists of an early date.

The French savant Perrey held that there was a connection between the moon's position and the occurrence of earthquakes, for he proved to himself that these phenomena were more frequent at the time of new and full moon than at the quarters; at the time of the moon's perigee than when in apogee; and during the winter months of the northern hemisphere than during the summer. His margin, however, appeared so small that eminent scientific men failed to perceive therein any positive proof. It remained for Falb to investigate these phenomena further, and to deduce from his investigations a theory, built up step by step from fundamental laws. It is this which he has within recent years advanced, and which has found enthusiastic adherents and violent opponents.

After having examined his authority for the assertion that earthquakes are subterranean volcanic eruptions, we shall proceed to investigate the second part of his theory, which ascribes to the sun and moon a considerable influence in bringing about the disturbances which we feel as earthquakes.

In examining the principal characteristics of an earthquake or tremor, Falb was led to consider the following :

1st. Three distinct modes of motion.—The moto succussorio, when the surface of the earth receives an impulse normal to it and rises vertically; moto undulatorio, when the surface is agitated in the manner of ocean waves; moto vorticoso, a twisting or whirling motion accompanying violent shocks.

2d. The nature of the principal or catastrophal shock.—All observed earthquakes go to show that the first shock or impulse is the most violent; that it takes place without any previous warning, beginning with a slight tremor, rapidly increasing within a few seconds to its full strength, and ending with a sort of an explosion.

The duration of this first shock is very short, but every shock of any violence at all is always followed by a series of secondary

shocks, which never, however, reach the intensity of the first, the principal or catastrophal one. He says that a single shock not followed by others is certain to be very light.

Falb lays great stress upon this, and claims it as a certain primary law, which had never been fully recognized and given the importance that it should command in investigations of this character.

The secondary shocks are usually very light, and are most frequent on the first day or two after the catastrophe; they decrease in strength from day to day until about the seventh day, when they again increase in frequency and strength for a short time. Not any of these secondary shocks ever reach the intensity of the primary or catastrophal tremor with which the series always begin.

Falb calls this law "the sequence of shocks," or simply "a sequence;" basing it upon numerous observations made during long periods in the earthquake regions of South America and in Europe.

I have examined a "List of Recorded Earthquakes in California, Lower California, Oregon and Washington Territory," by Professor E. S. Holden (Sacramento, 1887), with this point in view, and I became satisfied of the existence of the sequence.

Take those cases that are classed as destructive; that is, let us apply it to those instances in which the typical character would be most marked and the record most reliable.

October 8th, 1865.—Heavy earthquake at San Francisco. "The shock was felt sixteen minutes before one o'clock (P. M.), and lasted perhaps five seconds. It was *almost instantly* followed by a heavier shock, which continued for ten seconds or more." "On October 8th, in the evening, there were two or three slight additional shocks." On the days following more tremors are recorded of less severity.

"October 9th.—Light shock at San Francisco. After this shock the earth continued to vibrate for forty-eight hours."

October 12th.—"Constant tremors in San Francisco. (Fuchs)"

October 21st, 1868.—The great earthquake at San Francisco. The sequence of shocks after the catastrophe at 7:53 A. M. is brought out very prominently. Slighter tremors were felt all day, and for a number of days following.

March 26th, 1872. — Great Inyo County Earthquake, the severest of the century in California. "The shock was felt as far as Winnemucca, Nevada—462 miles east of San Francisco." * * * "The shocks continued up to April 10th, at intervals of a few hours, and in the mountains near by explosions were frequent, resembling distant artillery."

In the destructive earthquake of January 9th, 1857, which was felt from Fort Yuma to Sacramento, it is not stated that the violent tremor was followed by others on the same day, although a number of shocks are recorded from day to day in various localities of California, and strong tremors on January 20th at Santa Cruz, Fort Tejon, and Mission San Juan. It is difficult to say whether these shocks could be admitted as a sequence of the disturbance on the 9th.

It is found that in some cases a slight tremor will precede the catastrophal shock by some minutes, perhaps, but it is nowhere recorded that a violent or destructive shock was ever followed within a reasonable period by one more so. There is manifest throughout a *decreasing* scale of intensity in any one sequence of disturbances.

During the earthquake period, from October 21st, 1868, to November 16th, there are about fifty shocks recorded that are headed by the catastrophe on the morning of the 21st. Those who have felt these shocks know that in their very perceptible sequence not one of the secondary impulses ever reached the intensity of the starter on the morning of October 21st; that the primary shock was not preceded by light tremors to give warning, as it were, but that it came suddenly, with all its terrible consequences, to throw the city into the greatest excitement within a moment's time. For this particular case, therefore, we would have no reason to mistrust the law of sequence, which is a portion of the foundation upon which the Falb theory rests.

3d. The noise which usually accompanies an earthshock.—This peculiar rumbling generally precedes, but may also follow, a series of shocks. Its volume does not seem to be proportional to the strength of the oscillation—it may even be lacking entirely. The tremendous noise, known as *el gran ruido*, is said by Humboldt to have occurred from eighteen to twenty minutes

after a catastrophe, without any trembling of the earth at the time of the noise. It is also mentioned by him as having occurred in Guanaxuato, lasting from the 9th of January, 1784, for over a month, causing the greatest excitement among the inhabitants, who fled from the town in terror; and yet no other phenomenon accompanied or followed this noise. Not the slightest earth tremor had been felt during this strange occurrence, or after it.

4th. The electrical condition of the atmosphere during heavy shocks, which may manifest itself in lightning-like flashes, that illumine certain quarters of the heavens.

"During the long tremors of the earth in the Piedmontese valleys of Pellis and Clusson, the greatest change in the electrical tension of the atmosphere was noted, although the sky had been clear."—Humboldt—*Kosmos.*

5th. Tidal Waves.—It has been frequently observed that after a heavy earthquake near the seacoast, immense waves would approach the coast, encroaching upon the land much further than any of the known high waters. During our great earthquake in October, 1868, there was noted "an unusual commotion in the sea, and the waves came fifteen or twenty feet further inland than usual."—(Holden's List of Recorded Earthquakes.)

Falb distinguishes three different kinds of flood waves, depending in their character upon the position of the central point of the impulse in reference to the shore line; that is, the earthquake is either far out at sea, or at sea near the coast line, or on the coast near the seashore. The propagation of the wave would depend upon the location of the center of the disturbance. Fifteen minutes may elapse between the time of the primary shock and the approach of the tidal wave.

6th. Changes in the level of the coast and sea bottom, as well as changes in direction of ocean currents.—This has been observed after severe catastrophal shocks near the seacoast.

7th. Heavy rainshowers after an earthquake.—Humboldt mentions the fact that in tropical America, rain would fall at unusual periods, following heavy earthquakes, and that the natives look to oft-recurring tremors as indicating a fruitful season.

8th. The area over which the tremors are distributed.—An earthquake felt in a certain locality is most violent (though not most destructive) in one particular point, called the epicentrum, which receives the first impulse vertically from below. From it circular waves are transmitted, which decrease in intensity as they leave this center. The vertical motion must be greatest in amount at the epicentrum, from which the horizontal motion begins. But, although the intensity of the latter decreases at a certain ratio, there must be at some distance from the center a locality, in which the most destructive effect is felt, for it is apparent that horizontal motion is more destructive than vertical motion, and destructiveness is the characteristic which appeals more directly to our senses. Outside of this circle the intensity of the wave rapidly decreases, until the effect is no longer perceptible.

The area of tremor becomes of great importance, because from it we may draw some conclusions as to the depth from which the shock originated. Various methods have been devised for computing the depth of the focal point, but I am not prepared to say that any of them lead to very trustworthy results. As earthquakes are more generally observed, a method will be found by which the elements in the case can be more accurately determined. Our present theories suffer from a lack of sufficient data, but science, which has devised them, would soon perfect them, were it furnished with the necessary amount of material, without which theories remain uncertain. It may be of interest to state the depths at which the focal point has been estimated. In a number of cases in Europe, where the results may approach the truth, depths have been computed at ten, thirteen, and twenty miles. The Charleston earthquake has been estimated at about twelve miles. But the cause of the shock, in all these cases, must be looked for at still greater depths.

It has also been observed that the area of tremor is more or less elliptical. Humboldt says that the "Transmission usually takes place in linear direction, wave-like, in circles or large ellipses of tremor, in which, as from a common center, the vibrations are transmitted with decreasing intensity towards the circumference."

Falb holds that these waves generally tend to spread in the direction of the axis of the mountain range near which the shock occurs, and that this tendency would cause to make the area more or less elliptical.

9th. The distribution of earthquakes locally.—We all know that earthquakes do not occur with equal frequency in every part of the globe. There are localities where they never occur, others where they are periodically felt, and regions where they are a common occurrence. Where there are high mountain ranges, they generally take place with greatest frequency and force, particularly near the equator; in the tropics are these phenomena most numerous, while the temperate zone is comparatively free from them. In the vicinity of active volcanoes a trembling of the earth is quite a common occurrence.

10th.—The frequency of earthquakes in reference to the months of the year, which will require our attention further on.

Having the ten conditions just enumerated before him, Falb began to propound a theory in which each should be fully recognized and duly accounted for as an existing factor. All earthquake theories heretofore advanced do not satisfactorily explain these accompanying phenomena, which a long experience in this specialty had taught him as unmistakably connected with violent tremors of the earth.

The factors we have brought out in the preceding paragraphs are the foundation stones, hewn by Falb during years of industrious and energetic labor; upon them he built his final theory, and whether this building will stand or fall, will depend in great measure upon the soundness of the blocks which constitute the foundation.

Of earlier theories, and there were several (we do not need to enumerate them), one held that vapors produced by the earth's molten interior exerted a pressure against the crust, and that volcanoes are the safety valves that prevent this force from bursting the shell of the earth.

It was usual to ascribe earthquakes to different causes, and a particular distinction was made between two kinds of disturbances: volcanic earthquakes and those not of volcanic origin.

We quote from Humboldt, *Kosmos:* "Heavy earthquakes are felt in localities where there are inactive or even active volcanoes, without stimulating the latter to any perceptible activity. During the great catastrophe of Riobamba the volcanoes Tungurahua, near by, and the somewhat more distant Cotopaxi, remained inactive. Contrarily, volcanoes have been violently eruptive for long periods, and neither before nor during the eruption have earth tremors been felt. The most destructive earthquakes that history records, those which have agitated thousands of square miles, are the very ones that have had no perceptible connection with the activity of volcanoes. These have of late been called plutonic earthquakes, to distinguish them from those of volcanic origin, which are generally confined to areas of small extent. In consideration of the more general views regarding volcanicity, this nomenclature can not be sanctioned. The greater number of earthquakes upon our planet should be termed plutonic."

Then Humboldt groups the phenomena in three characteristic types:

1. Earthquakes confined to areas of small extent, evidently due to the activity of a volcano. He has observed them himself, while sitting near the crater of Mount Vesuvius, to precede frequent eruptions of hot clinker. These slight earth tremors, felt at regularly-recurring intervals, were only noticeable in the immediate vicinity of the crater.

2. "A most important group, frequently occurring: Earthquakes which may accompany or precede volcanic eruptions, be it, that the volcanoes bring forth lava streams, as our European mountains, or, like Cotopaxi, Pinchincha and Tungaragua of the Andes chain, only clinkered masses, ashes and vapors. For this group volcanoes are looked upon as 'safety-valves.' The earthquakes cease when the great eruption has taken place."

3. "The most general group, however, is that of which the tremors disturb non-volcanic and volcanic countries alike, without influencing the volcanoes existing in the latter. These phenomena remind one most convincingly of a common cause to be looked for in the thermal condition of our planet's interior."

And he finally concludes by saying: "I have thought it useful to enumerate all the differing manifestations of the same

volcanic agency (the reaction of the earth's interior against its surface), to aid the observer in creating a material which might ultimately lead to fruitful results regarding the causal connection of these varying phenomena. Sometimes the volcanic activity embraces at the same time, or in closely-following periods, so vast a portion of the earth that the tremors at the surface may be attributed to several causes individually related."

I have here extracted at length from Humboldt's "*Kosmos*," because it illustrates the diverging views that existed at that time, and shows that that great man, to whom every theory in physical science was known, did not surmise in what manner effects so much at variance with each other might be traced to a common cause. Is there any more reason for attributing earthquake phenomena, which are in the main exactly similar, to different origin, than it would be to ascribe, for instance, rain-showers to one cause to-day and to another to-morrow, because the accompanying conditions may be at variance?

Here Falb takes a decided and positive stand. Earthquakes have only *one* cause—they are all of *volcanic origin*, whether there be volcanoes active or inactive or none at all; whether they occur in mountain regions or on plains, in the Andes or on the Nether Rhine; whether they create the wildest excitement in San Francisco, or death and destruction at Charleston, the cause is always and invariably the same. And that which causes an earthquake also causes volcanic eruptions perceptible to the sight. These two phenomena are of the same origin; they are links in the same chain of events; members of the same family in three generation: for disturbances in the earth's interior beget volcanic eruptions, and volcanic eruptions beget earthquakes.

We begin to see now what Falb means by the conclusion that heads this paper: "Earthquakes are *subterranean* volcanic eruptions"—and that, of course, necessitates the supposition that under the surface of the earth there exist volcanoes, subterranean craters, at greater or less depth beneath our feet, which are not in any way perceptible to us on the surface.

Before proceeding further, it is well to state that the main foundation of Falb's theory is this: that our earth still is and

always has been a cooling globe; that it was at one time a fiery ball, and that by gradual cooling the hardening crust has constantly encroached upon the interior heated mass. I am aware that we can furnish no other proof for this than that which was made the fundamental principle of the evolution of planetary worlds as advanced by Kant and Laplace. Conclusions have been brought out that the earth's shell must be of immense thickness; and, based upon physical principles, the announcement has been made that the earth may even be solid altogether. Yet, of all theories regarding the earth's crust, it is admitted, as Dana says, that a liquid interior, or a liquid layer between the crust and a solid nucleus, as argued by Hopkins, will meet all requirements of geological science.

The conception of an interior fluid washing the inner surface of the crust does not seem to present a probable condition. Geological investigations have shown that the shell of the earth may be a thousand miles thick, and the tremendous pressure of such a layer must cause peculiar atomical and chemical conditions interiorly of which we can form no very accurate conception. The heat, as the result of the pressure, must become so great as we descend, that at a certain depth difficult to determine, it must be sufficient to fuse all solid matter. But the high degree of pressure would in itself be a cause to prevent that very condition which is necessary to our comprehension of a fluid, i. e., that the particles must be free to move around each other. It is readily seen, that any variation in pressure would disturb the equilibrium which holds gases and fluids in such critical condition. Every disturbance would necessitate an adjustment, and the manner of this adjustment is volcanic action.

[Later antagonistic theories dispute the necessity of a direct volcanic action for such adjustment. The idea of separate causes for earthquakes of different degrees of violence is still clung to, and it is claimed that the so-called tectonic earthquakes have nothing whatever to do with our globe's volcanic activity.]

To proceed: We shall assume that condition of the earth's interior, which Falb has made the basis of his theory, and explain volcanicity as a cosmical phenomenon, the direct result of

a cooling process which fiery fluid masses undergo as they radiate their heat into space. This holds good for all celestial bodies that are hurled along their endless paths. Cooling means contraction, and consequently an increasing pressure upon the interior mass. This contraction on the one side and expansion on the other, are two eternal forces at war, two cyclops doing battle in the infinite fields of the universe.

Analogous processes have been observed on the sun. The flame-shaped protuberances, extending from the circumference of that mighty orb, are known to be driven up masses of hot hydrogen gas. During a solar eclipse they appear to us like the jets of plutonic fountains, casting their fiery spray into the sombre region of dismal space. What we behold is an eruption on the mightiest scale. We witness the battle of the two cosmical forces where both combatants are in vigorous action, and where the fury of the fray is thrown against the solar sky, like the smoke that arises from a battle-field of nations. Upon our earth one of the cyclops is a prisoner; contraction holds him bound, but it has not at all subdued him. There are times when he is aroused to renewed and fearful activity, when he may break forth from his cell, carrying death and destruction before him; or, in his attempt to break his fetters, he may shake the prison walls until they tremble from foundation to bastion. Yet, mastery rests with the giant contraction; he is as inevitable as death, the victory must ultimately be his. Look to the moon! The war there is ended, the last battle has been fought ages ago. When her pale light illumines the battle-field, we see the evidences of the fight. Numerous cavities and craters, pit-like openings, seem as though the fury of the battle had furrowed them; circular wall-like mountains surrounding a central range appear to us like the ruins of gigantic fortresses, thrown up when the enemies brought all their forces into action. And now the lunar mountains cast their spectral shadows over the valleys of cosmic death. Volcanicity, the sign of cosmic life, has disappeared. This must be the inevitable fate of every body that is hurled through space. The future, therefore, predicts an ultimate end of the universe, when contraction, with its icy grasp, has throttled the life out of every world therein. But ex-

pansion has been storing new forces in another region, which will be brought out in their turn. This is the heat radiated into space of which nothing has been lost. This heat is an ever-increasing force, a mode of atomic motion of some subtle element, upon the capabilities of which we can only conjecture. It may inspire new cosmic life to worlds that are to come, and store a fresh vitality for new spheres from the departed energy of the old; so that cosmic death may mean cosmic life—an eternal cycle of changes without beginning, without end. And thus an endless chain of ever-recurring events in the cosmogony is conceivable. It is "a circle that ever returneth into the self-same spot." With light and life the young phœnix arises from the ashes of the old; with light and life the triumphant conqueror is heralded into the vastness above, below and everywhere.

Volcanicity, therefore, is the vital principle in the life of our earth. It is manifested to us in terrestrial disturbances, visible as in an eruption, or perceptible as in an earthquake. To prove the similarity between the former and the latter, Falb first attempts to demonstrate how a volcanic eruption is brought about; then gives a physical reason for each characteristic feature; and finally endeavors to show that the two phenomena are analogous.

The shell of the earth must be conceived as perforated by canals, rent by deep cracks and fissures, a natural consequence of the very vigorous volcanic action when our planet was younger and the crust thinner. Some of the flue-like passages may reach the surface, or they may terminate below without an exterior outlet.

The volcanic force cannot break through the immense shell of the present; it cannot effect new passages, but will rather confine itself to and seek the direction of the old highways. These are most likely to terminate in those regions where, in the early history of our planet, it offered the least resistance to the internal force. Deep fissures, although covered by surface layers, will thus be apt to remain the roadways, particularly if the water have free access, and by infiltration keep the material

saturated—a likely condition near the seacoast, where water may be infiltrated to great depths. This moisture may be vaporized by the heat of ascending lava, and the resulting pressure would be a factor to keep these openings free.

Lava, as emitted, is described by Falb as a product resulting from the melting of materials forming the earth's crust (matter which had already been solidified), and brought up from all depths in a fluid state, but never is it a part of the fiery fluid kernel itself. He says that heat emitted from the latter penetrates into the deeper fissures and melts the solid material adhering to the walls of the cavities and passages. These smelted products are of lighter specific gravity than the central mass subjected to the immense pressure of the crust, and therefore constitute the surface of the interior kernel, which is cast out as lava. This also accounts for the diversity of the chemical combinations of the lava of different volcanoes, depending as it does, upon the mineralogical character of the underlying strata of the crust.

The pressure which cooling and contraction exert upon the interior mass, forces this lava into hollow cavities and passages that communicate with the exterior layers of the shell. Falb compares this process with the rising and falling of a barometer, for with a constantly varying pressure the lava column may be conceived as constantly either rising or falling. If in its ascent it come in contact with the infiltrated water from above, vapors and gases will be generated, which will cause to increase the upward pressure against the solid material choking the passage, and likewise exert a pressure against the ascending column. The rising lava compresses the gases between it and the stopper in the tube, and this process may quietly go on beneath our feet, and nothing indicate to us the approach of the secret enemy. The stopper, consisting of volcanic debris, clinker and stone, is gradually pushed upwards; between its interstices there may at first be some escape, which will amount to but little when we consider the ever-increasing force under it, for the nearer the lava gets to the surface, the more of the infiltrated water will be vaporized, and the pressure correspondingly increased. The heat, too, will have the effect of melting together the masses of

the stopper, and this accomplished, the exit of the canal is hermetically sealed.

During all this time no earthquake will be felt, no trembling to give fair warning of a catastrophe approaching, that in the history of the world has time and again caused death and disaster, and laid waste fertile plains and thriving cities. Herculaneum and Pompeii lay buried for centuries under the mantle of death, which relentless nature had cast over them. Little did the inhabitants think of the dire calamity in store for them, while in earth's deepest recesses the preparations were going on that we have described, until the rising lava and its precursory gases and vapors had brought about that degree of pressure necessary to remove with violence all the material closing the mouth of the flue, like forcing the cork from the mouth of a bottle, when the eruption followed with its indescribable horrors so suddenly that there was no escape from the far-reaching finger of fiery death.

If, as in this case, the flue or canal reach the surface, nearly all the energy is imparted to the air, and we have a visible volcanic eruption.

The cast up materials appear in regular order. First of all the stopper flies out, the choking volcanic debris, which had accumulated in the passage and effectually closed it; then follow the gases and vapors, which, rising over the mountain, suddenly cool, thereby causing rain-showers with electric phenomena, lightning flashes followed by loud thunder peals; the fine ashes melted by the hot vapors causes a most general occurrence, the outburst of mud; then follows the lava stream, which will quietly flow from the orifice like an overflow of the Styx.

In cases where after the outburst of mud lava does not flow, this reason is given: the lava column has already receded, that is, the upward pressure is no longer sufficient to raise it to the required height. This is the case in localities where volcanicity is decreasing in intensity. Such localities may show lava beds of past ages buried under later deposits; the falling off of the temperature of the deeper regions has lessened the volcanic activity, and at recent periods lava has not been brought to the surface.

It has been observed, however, that if an eruption occurs after a long rest of a still vigorous volcano, lava will generally flow.

But to return to the eruption: After the lava stream ceases, it will slowly retreat, that is, fall in the tube, and air will rush into the empty canal of the crater. A vigorous upward current will be created, assisted by ascending gases, and this will cause a scouring of the walls of the canals and passages leading from the orifice downward, and all those diverse products of combustion adhering to the walls will be carried upward into the air, and descend as a dry rain of volcanic ashes.

After the retreat of the lava, earthquakes are felt; at first and in some cases only in the vicinity of the summit perceptible, they after a time shake the neighborhood surrounding the foot of the mountain frequently and with more or less violence.

Falb accounts for these tremors, and traces their origin to the following causes:

While the lava column is retreating, bubbles of gases and vapors will rise from its lower depths to its surface, like the carbonic acid in a champagne bottle after drawing the cork. As long as the cork was there, this could not happen, but when the obstacle is forcibly removed and the pressure released, and the lava slowly retreating and gradually cooling, gases will develop and rise from all depths of the column, winding their way up to the surface, where these bubbles will burst with a violent explosion, whereby clinker and fluid particles are hurled up to considerable height. Bubble after bubble will follow rapidly upon each other, and the explosions therefore may be observed at regular closely following intervals.

This explains the characteristic which Humboldt observed, to which we have referred heretofore, tremors which he noticed following closely upon each other, while sitting near the crater of Mount Vesuvius after an eruption.

It is hardly necessary to state here, that the height of the lava column at the time will determine the elevation at which the ground is observed to tremble, for if these explosions should occur above the level of the surrounding plain, earthquakes will be felt on the mountain only, but if the lava have sunk to a sufficient depth, the locality in the vicinity of the volcano will feel them.

Tremors of this kind will last for several days, depending upon the speed at which the lava recedes. The character of the eruption qualifies the degree of violence and the frequency of these shocks.

It is noticed how much at variance this theory is in one respect with the ideas of older text books, which taught that volcanoes did duty as a sort of a safety valve to the great boiler (designed on purpose possibly to protect mortality), and that earthquakes cease after the eruption has taken place—when the steam has been blown off. Even Humboldt makes that statement, but it is now safe to assume that this is not so. Earthquakes follow an eruption very likely in every case, but they are not always perceptible except in the immediate neighborhood of the volcanic outburst. The tremors do not cease, but rather begin after the eruption.

In volcanoes that have been inactive for centuries, where the exit has been so effectually closed as to resist the pressure, the most violent earthquakes may shake the vicinity of the mountain and the eruption fail. Or, if the impulse be of sufficient moment, a vast portion of the side of a mountain may be carried away, if it offered less resistance to the attacking force than the sealed outlet of the old flue. In such an event all the phenomena we have described will be manifested, except perhaps the eruption of lava, which in the case of an old volcanic region, is not always a necessary feature, for reasons already given. But all the other usual characteristics will follow in their order after the terrible explosion: the outburst of mud and of stones, carried away to considerable distance, flashes of lightning, rain-showers, and the final descent of the ashes, which adds that sombre darkness to all the horrors of this fearful and awe-inspiring scene, together with indescribable noises and the hissing of numerous jets of steam, proceeding from the opened fissures and canals that lead to the interior vaults of our earth's mysterious laboratory.

From all such facts as we have thus described and brought out, our authority has come to the following conclusions, which find their foundation in his carefully collected data. We have all

been acquainted with the greater number of them, for they have been mentioned in connection with other theories before, but I shall again give them, taking them in the order in which Falb enumerates them, to show each link in the chain of events, and to give us a clear undertanding of his theory.

(1.) Volcanoes generally appear in rows along a straight line; explained by subterranean fissures.

(2.) They are almost exclusively near the sea; explained by the infiltrated water coming in contact with the rising lava.

(3.) Some time before an eruption the smoke from the mountain increases; explained by the interstices in the choking material which closes the outlet.

(4.) Shortly before the eruption the smoke entirely disappears; explained by the melting together of this mass.

(5.) All is quiet before the eruption; explained by the pressure of the lava from gases between it and the stopper.

(6.) Solid masses are first thrown out with the eruption; explained by the choking mass referred to.

(7.) Local rain-showers with lightning and thunder follow; explained by the condensation of aqueous vapors.

(8.) Eruptions of mud follow; explained by the mingling of vapors with the fine, ash-like dust in the flue.

(9.) The eruption of lava is not always necessary; explained by the retreat of the lava after the release from the pressure of gases and vapors.

(10.) An upheaval of fine ashes completes the eruption; explained by a current of air scouring the flue, and the formation of ashes after the descent of the lava.

(11.) After the eruption earthquakes occur; explained by the explosive activity on the surface of the lava now relieved of all pressure.

(12.) Between the eruption of the volcano and the earthquakes in its vicinity several hours elapse; explained by the time re-

quired for the lava to sink below the level of the foot of the mountain.

(13.) The earthquakes are numerous and follow in rapid succession; explained by the very active emission of gases and vapors from the lava, as soon as the tremendous pressure above it is removed.

The earthquakes which are generally felt after an eruption led Falb to seek a connection between them and those secondary shocks of a sequence that follow the catastrophal shock. If the sudden outburst of a volcano be assumed as the primary impulse, the earthquakes—which are felt either on the mountain or in the vicinity of its base after the eruption — are nothing more or less than the sequence of secondary shocks that follow in the wake of the principal tremor that heads the list. Exactly similar conditions have produced these phenomena, but their origin in the latter case is not so apparent.

If we grant the existence of subterranean volcanoes and their capabilities of becoming eruptive, we shall have no difficulty in explaining every tremor that disturbs the earth.

As the cooling of our planet continues, the time must come when volcanic action has ceased to be a visible phenomenon at all; when, far distant though it may seem, even the volcanic mountains themselves will have been leveled to their foundations by the action of the water and air. Cities and villages may thrive in the very localities where to-day nature's battles are fought with unremitting violence. But in that dim future the great forces of the lurking enemy are not all subdued. They are yet there, in prison walls beneath our feet, better secured perhaps, but still capable of raising an occasional rebellion. This far-off period is sure to come; slowly and imperceptibly to us, for nature in her great works knows no limit of time. If the lava in its subterranean canals can no longer be raised to the surface, it may yet rise to a certain height, depending upon the intensity of the lifting force; and as it is brought in contact with sub-surface moisture, resulting vapors will cause eruptions at a greater or less depth beneath our feet. When volcanic activity can no longer be seen, it will still be

felt, and earthquakes will remind us that Vulcan has not ceased to wield his mighty forge.

Falb makes a very positive statement to the effect that the possibility of an eruption, an outbreak of vapors, gases and lava into subterranean hollow cavities, cannot be disputed by any argument of weight. With this very bold assertion he announces his final decision, and claims it as a law of nature, that "earthquakes are eruptions of subterranean volcanoes, the direct cause being the cooling of the earth."

He may not have convinced you; you may take exceptions to some of his statements which do not seem based upon sufficient data to prove them with certainty; there may still be factors in the case, and there undoubtedly are, which he could not and has not considered; but are we not dealing with a theory which merely strives to account for the mechanical features of the event as far as they are known?

We began this paper by enumerating all those various characteristics which impressed themselves upon him as the principal factors to be accounted for, for every one of which he has found an explanation in harmony with his theory.

I have not the time to go over each item at present; any one may make the comparison at his leisure, and he will find no difficulty in discovering the manner in which Falb would account for each characteristic feature of an earthquake by taking the subterranean eruption theory as a basis.

The various modes of motion; the roaring noises; the tidal waves; the principal or catastrophal shock, which is due to the sudden explosive character of the beginning of the eruption; the lighter secondary tremors following the primary shock, caused by the explosive activity on the surface of the receding lava (the bursting bubbles referred to, which are the lighter earthquakes that usually follow a visible eruption); the greater frequency of earthquakes in the tropics, due in a measure to the centrifugal force of the earth — all these features may be readily interpreted if we are willing to accept Falb's explanation of the cause.

And now we shall touch upon that portion of the Falb theory

through which the author's name has become most popular, in which he has not been without success, and whereby he gained a public prominence reaching far beyond his own country. I refer to the attractive influence of the heavenly bodies as an aid in causing earthquakes.

If we examine the months of the year in reference to the frequency of shocks, we shall find that they are not equally distributed. That of the whole yearly number a certain percentage will fall to each month. We shall notice in this distribution a regularity which can not be a matter of chance; and this may lead us to admit that the attraction of the sun, and, as we shall see, the moon, gives an important aid in bringing the phenomenon about.

Falb took from Mallet's catalogue the days upon which earthquakes occurred from the year 800 to 1843, a period of a thousand and forty-three years. In that time he collected 5,492 earthquake days for the northern hemisphere. The distribution was as follows:

January	583
February	496
March	451
April	455
May	427
June	377
July	388
August	424
September	403
October	517
November	465
December	506

If a curve be drawn (see Fig. 1) expressing a ratio of frequency, we shall find that most earthquakes occur in January, that there is a rapid decline for February and March, and a moderate increase for April; from thence the curve rapidly sinks and reaches its minimum in June, after which a rise is again manifested. In August a mid-point is reached, from which it

again drops for September, after which a very decided autumn maximum is shown for October; we then notice another decline in November, and thence a rapid increase to the January height.

In order to ascertain whether the character of this curve depended upon this particular collection of data, Falb divided the number of earthquake days in halves — one period extending from the year 800 to 1794, and the other from 1794 to 1843 — the first being about 1,000 years long, and the other about 50; the corresponding number of days being 2,751 for the long period, and 2,741 for the short one. It is evident that the data for the 50 years must be more detailed than that of the thousand year period, because the record of late years would naturally include the slight shocks which in the earlier centuries were not thought worthy of record by those who chronicled history. It must be admitted that two more uneven periods, both in regard to time and data, could not well be chosen; and yet, when we come to arrange and plot the values for the two periods in monthly sets, our attention is called to a similarity that is only too striking. The following table will illustrate this:

Months.	800-1794.	%	1794-1843.	%	Whole Period.	%
January	324	11.8	259	9.5	583	10.6
February	248	9.0	248	9.1	496	9.0
March	215	7.8	236	8.6	451	8.3
April	220	8.0	235	8.6	455	8.3
May	215	7.8	212	7.7	427	7.8
June	213	7.8	164	6.0	377	6.9
July	198	7.2	190	6.9	388	7.0
August	195	7.1	229	8.3	424	7.7
September	207	7.5	196	7.2	403	7.3
October	234	8.5	283	10.3	517	9.4
November	223	8.1	242	8.8	465	8.4
December	259	9.4	247	9.0	506	9.3

(See curves 2 and 3.)

We have said that these values represented a condition for the northern hemisphere; the question then naturally arises, How will the southern hemisphere compare, in this respect, with the northern half of the globe? Falb furnishes us with a record of 501 earthquake days, between the years 1862–1877, taken from

the official list of the lyceum at Copiapo. From it we learn the following:

(See curve 4.)

January	62	12 %
February	37	7 "
March	42	8 "
April	45	9 "
May	46	9 "
June	35	7 "
July	41	8 "
August	43	9 "
September	20	4 "
October	56	12 "
November	53	11 "
December	21	4 "

We can not help noticing a resemblance in all these curves, and perceiving that in both hemispheres the winter months of the northern are the most productive, and that during the northern summer the relative frequency is least. This fact becomes apparent in any number of combinations that we wish to try, the general character of the yearly curve manifesting itself in each instance.

Three thousand two hundred and ninety-nine earthquakes in Europe (Dr. Ule, "The Earth," cited by Falb) are distributable among the months as follows:

(See curve 5.)

January	363	12 %
February	298	9 "
March	284	9 "
April	254	7 "
May	280	8 "
June	227	7 "
July	238	7 "
August	258	8 "
September	238	7 "
October	287	9 "
November	252	7 "
December	320	10 "

Continuing these investigations, we applied this test to the earthquakes recorded for the western coast of the United States, as taken from the list compiled by Professor Holden.

His table for California, Oregon and Washington, 1850-1887, shows a total of 768 earthquake days, distributed among the months as follows (see curve 6):

January	68	9 %
February	45	6 "
March	66	8½ "
April	71	9¼ "
May	56	7¼ "
June	51	6½ "
July	45	5¾ "
August	53	7 "
September	85	11 "
October	88	11½ "
November	57	7½ "
December	83	10¾ "

For San Francisco we have for the same period (taken from the same list) a total of 254, bearing to the months of the year as given below (see curve 7):

January	25	10 %
February	22	9 "
March	26	10 "
April	15	6 "
May	17	7 "
June	17	7 "
July	13	5 "
August	11	4 "
September	21	8 "
October	35	13 "
November	30	12 "
December	22	9 "

Again, we find a certain similarity in the structure of these curves to all preceding ones, with the April and October maxima

a little too prominently developed, but with a decided minimum for the summer months.

Certainly, language can not speak plainer than do these graphic illustrations, as they bring out, at random as they are taken, again and again the facts to which we have called attention. Can this be a matter of chance? Would it seem so unreasonable to suppose that the January maximum may be caused by the earth's perihelion; the April by the sun's position in the equator (about March 20th, when two forces—the centrifugal force of the earth, and the attraction of the sun—are operating in harmony); that the June minimum may be due to the earth's aphelion, when the sun's attraction is least; that the October rise is brought about by the sun's reaching the autumnal equinox, September 23d; that the fall for November is due to the sun's increase in southern declination, and that as the earth sped towards perihelion the curve of frequency would again reach its greatest height?

Falb says there can be no reasonable doubt about it, and if these curves teach anything, they teach that nearness of the sun stands out as the principal factor, assisted perceptibly by the equatorial position of the sun, as a cause for the greater frequency at such seasons of the year.

If two curves, one representing the earth's departure from and approach to perihelion (which would represent the attractive force of the sun during the course of the year), and the other representing the sun's declination, or his apparent movement from solstice to solstice through the equinoctial points, be combined into one, similar characteristics in the structure of this curve to those we have drawn from earthquakes should manifest themselves. And if we developed such a curve, we should find that this fact would appear. It, however, would show a spring and fall maximum of the same height, whereas in the earthquake curves the October maximum is so prominent as to far overreach that of April. The reason given therefor is this: that at the time of the vernal equinox the line representing the earth's departure from perihelion is so rapidly descending, that the counter impulse due to the sun's approaching the equator is only sufficient to check

this descent somewhat; but at the time of the autumnal equinox the latter impulse is acting in the same direction with the former, it assists it in its rise; the two lines are ascending together, and the two forces in joint action would develop more prominently than under the first condition.

But since so much of an influence seems to be due to the attraction of the sun, does not the moon similarly play a most important part, as she is by virtue of her attraction the most prominent flood-factor influencing the earth?

The answer is, yes; and in order to make plain the attractive influence of the heavenly bodies upon our earth, we shall briefly enumerate the so-called flood factors to which Falb gives great weight in his theory. They are: the earth's perihelion; the moon's perigee; the moon's syzygies; and when either sun or moon are on the equator; or, as Falb puts it more concisely:

Earth's perihelion, - - - - - - -	I.
Moon's perigee, - - - - - - -	II.
Same or opposite right ascension of sun and moon, -	III.
Same or opposite declination, - - - - -	IV.
Equatorial position of sun, - - - - -	V.
Equatorial position of moon, - - - - -	VI.

The first and second factors find their explanation in the minimum distance of sun or moon from the earth, when their attraction would be greatest; new and full moon are too well known as flood factors to require any explication; and the equtorial position of these bodies, as the last named factor, is interpreted by the fact that the attractive influence of either body is exerted in the same line of direction with the centrifugal force of the earth, which latter is a constant, ever tending to hurl off masses tangentially and parallel to the equator, with a developed maximum at the latter, explaining also the frequency of volcanic disturbances in tropical regions. Any one of these factors has a certain weight as an attractive force, which may be augmented if any two or more of them fall together at the same time. It is clear that a number of combinations may be made. At the earth's perihelion, about January 1st, a new or full moon

may occur; with the syzygies we may have a perigee of the moon; and at the time of the spring or vernal equinox a number of the flood factors due to the moon's position may be augmented by the sun's equatorial position. The greatest number of these factors that can at the present time occur together, are four or five, never all six, as shall be shown further on.

Of the most prominent combinations we have—

I, II, III, IV,

which would be at the time of an eclipse near January 1st, together with a perigee of the moon—a condition, by the way, nearly fulfilled on New Year's day of this year; or,

II, III, IV, V, VI,

satisfied by an eclipse near the time of the equinoxes with a moon's perigee. At the time of solar or lunar eclipses, therefore, the attraction of these bodies upon our planet develops to a most conspicuous factor, finding its explanation in the fact that sun and moon combine in their effort to influence the earth, by being in the same line of direction.

Observations have shown sufficiently that earthquakes at the time of an eclipse are not an uncommon occurrence. Falb says that history has recorded that fact too often to doubt it. Within recent years we have had an occasion to note this.

From a number of cases cited by Falb, the following are taken: Two disastrous earthquakes, independent of each other, occurred in 1886; one in Morea on the 27th of August, and the other in Charleston on the 31st of the same month. A solar eclipse took place on 29th. In 1888 three eclipses happened within a month. A solar on July 8th, a lunar July 22d, and a solar again August 7th. Note the great catastrophe in Japan on July 15th, within that period.

If it were possible to construct a curve by taking all the flood factors consisting of sun's distance and declination, moon's distance and declination, moon's syzygies, etc., from an almanac, and plotting them with relative values to their

proper date for a whole year, and then combining them, this line would show elevations and depressions according as these factors fall upon or from each other, and we would have a graphic curve of reference, which by its prominences would point to certain dates when the flood factors in combination are exerting their maximum influence, and when earthquakes might be expected. This probability curve would not only exhibit periods, but dates when the condition for earthquakes would be favorable. I am far from agreeing with those sanguine believers in this theory, who hold that seismic disturbances could be foretold upon this basis, for it is certain that the flood factors are not the causes, but that they are simply an aid in furthering or perhaps hastening an event about to take place. An adjustment between contraction and expansion may lie at the very point of occurring for some time, until a very trifling circumstance may add weight enough to the balance to cause one end of the scale to go up. We may liken it to the burning match applied to a powder barrel, or to the last straw that breaks the back of the camel.

Volcanicity is the result of opposing cosmical forces, regardless of the attractive influence of the heavenly bodies; that is, *earthquakes would occur without sun or moon, but it is fair to assume, that in that event they would be equally distributed through the course of the year.*

I experimented with a curve which I had projected for the maximum and minimum influence of these factors for 1888, and followed with great care all recorded seismic disturbances for that year, comparing them with my probability curve. It is impossible to draw any conclusions of weight from the observations of a few months with the limited amount of data to which I had access. I am ready to state, however, that in most instances I have been surprised by the coincidences of the moon's syzygies with perceptible earthquake shocks.

I am not prepared to state, from my own studies, how much weight proportionately is to be given to each factor in constructing a curve of that kind, and am not ready to admit any prognostication of these phenomena, although Falb has with great success foretold a number of volcanic eruptions and seismic disturbances with remarkable exactness as to time, as well as in

some instances to place. The simple fact, however, of the influence of the position of the sun and moon upon the volcanic life of our planet can no longer be denied.

During the year 1888 the great eruption of Bandai San, to which I have already referred, took place on the 15th of July; a most disastrous catastrophe, occurring without any warning, during which nearly five hundred people lost their lives.

This disturbance happened when the minimum point of frequency in the curve which I projected had just been passed, when the probability, therefore, was small, but it took place during a period which Falb calls very critical—at a time when the three eclipses, which I have mentioned, occurred within a period of 30 days — and these factors are of such weight in the estimate that he would give them sufficient importance to connect them with the particular time of this disaster.

Again, a number of seismic disturbances occurred about the autumnal equinox, from the end of September into October. September 25th severe shocks were felt at Guayaquil; they were followed by flashes of lightning. The people were panic-stricken. At Helena, Ecuador, a sharp earthquake was felt September 25th. On the 26th a violent disturbance was reported in the Gulf of Persia; and a number of others were announced in the telegraphic news for October.

The eclipse of the sun on January 1st, 1889, occurring at the time of the earth's perihelion, should have been a very critical period, and I watched that event with particular interest. Although I did not learn of any catastrophal convulsion at that time, I gathered quite a number of items of reported earthquakes. I have notes recording them for Spain, Mexico, England, Costa Rica (very severe), and Russia, which occurred within a few days on either side of the eclipse.

A few days ago I cut from a daily paper a notice of severe earthquakes in Ecuador, which I append:

"St. Elena (Ecuador), March 3d, 1889.—A sharp shock of earthquake was felt here last night. It lasted about 15 seconds, and was followed a few minutes later by four other shocks. Shocks were felt at intervals during last night and to-day."

"GUAYAQUIL (Ecuador), March 3d.—A violent shock of earthquake was experienced here last night. During last night and this morning there were thirteen other shocks of less severity. * * * A panic prevails among the people."

We see therein the character of the first or catastrophal shock well brought out. The secondary tremors following it as a sequence are quite in harmony with the theory. In regard to the date, March 3d, we shall find two flood factors near each other, viz: new moon, March 1st, and moon on equator, March 3d. Most weight must be given, however, to the approach of the vernal equinox, for the curve teaches us that this is a critical period. Earthquakes may, therefore, be expected from now on until the sun's northern declination has increased sufficiently to lessen the weight of this factor. But in making this statement it should be remembered that I have called attention to the fact that an earthquake may come at any time without interference of sun or moon, and it is therefore not safe to prognosticate to any particular date by applying a calculation with the time of the occurrence of flood factors as a basis. Were mathematical determinations only required, events might be foretold with the greatest accuracy; but in the matter of earthquakes and the volcanic life of our globe we deal with the planet's organic existence, wherein a purely mathematical demonstration can never be sanctioned.

This is a hasty sketch of Falb's theory. It differs from others in laying claim to *one* exclusive cause for all earthquakes, which is a point of objection to a number of scientists. Many who admit volcanic action as the direct cause for the great earthquakes of our globe are not willing to account for lighter tremors in the same way.

Another explanation is sought in the "orogenic" theory, which claims earthquakes as the active signs of the mountain-building forces of the earth. The crust is in a condition of constant tension, by reason of the gradual and continuous cooling; from time to time the equilibrium is suddenly disturbed in the lines of greatest tension, and this causes the tremors.

The volcanic theory, however, has taken a very prominent

place in this field of research, and is very likely to retain it, as it offers a ready explanation for the prominent features of an earthquake, particularly if of any magnitude.

The influence of the sun and moon is not denied by other scientists, but they are not ready to give it the importance that Falb does.

The well-known seismologist Fuchs, in referring to Falb's theory, says:

"If we oppose this theory our opposition is directed, first of all, not against its assertion as such, but against its exclusiveness. After a great many causes for earthquakes have been pointed out we might also discuss the influence of the moon, but we cannot admit a theory which alone claims to account for all earthquakes."

This statement had particular reference to the influence of the so-called flood factors.

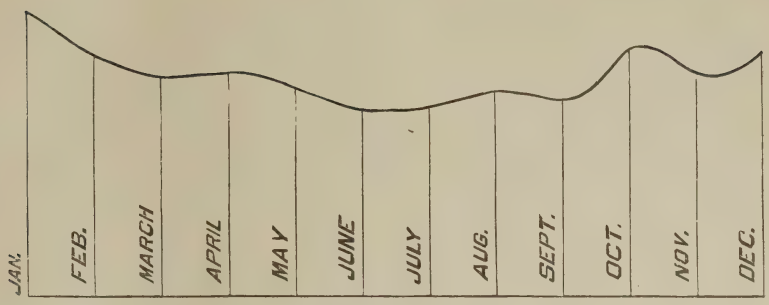
Be these controversies as they may, it is interesting to follow an energetic man in his conscientious labor, and it should stimulate others to give their attention to this field of physical research. What is particularly needed in every community is the facility for making seismographic observations. Facts should be gathered everywhere by all who care enough for mother nature's voice and acts to listen and to watch; and eventually we may, from our collected data, see the law, if there be any, develop itself.

I would yet like to call your attention to the fact, that two of the prominent flood factors cannot, at the present time, occur together. They are: the earth's perihelion and the sun's equatorial position. The former occurs about the 1st of January, and the latter March 20th and September 23d. This has, however, not always been so, for the point of perihelion, not fixed as to date, increases in longitude about 62″ annually. A complete revolution of the line of the apsides is therefore made in 20,900 years, which would carry us back about 6,000 years to the time when the perihelion coincided with the autumnal equinox. Here two of the most important factors fall together; in fact, all of them may occur at that time. Falb looks to this fact as an explanation of

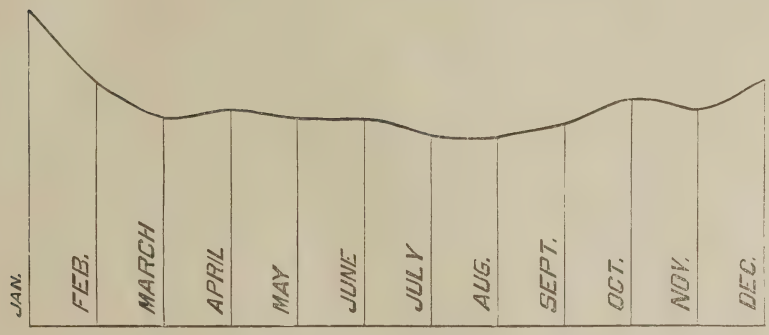
the Deluge, which tradition places at the time when the most favorable position of the sun as to distance coincided with that of direction. The ascending equatorial current carries with it the aqueous vapors caused by evaporation in the tropics. The greater the evaporation the greater the amount of moisture carried away and elsewhere precipitated. We can readily see the connection without going into further details.

A critical period of that character may, of course, be again expected, with all its disturbances, about 4,500 years hence, when the earth's perihelion will fall together with the vernal equinox.

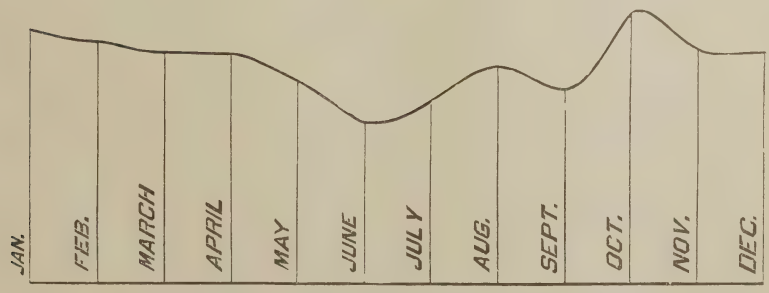
I am quite ready to prognosticate such an event, partly because I have faith in this theory, and partly because you wouldn't have the laugh on me if it did not turn out so.



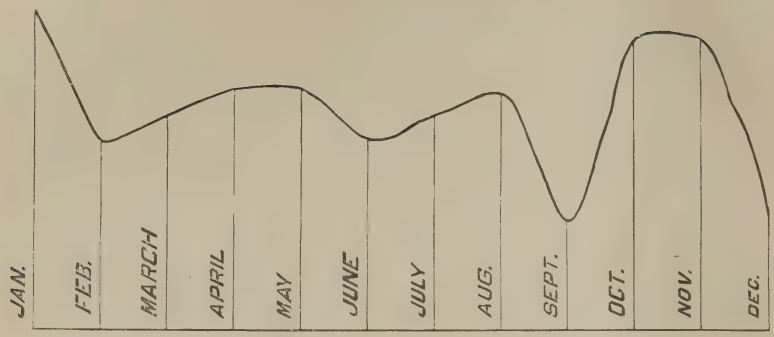
No. 1. From 800 to 1843. (5492 cases.)



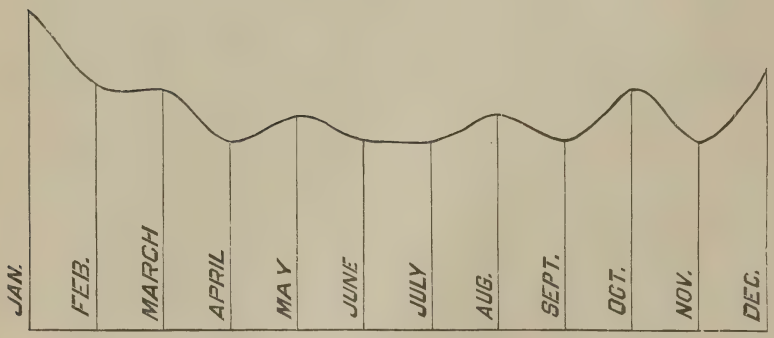
No. 2. From 800 to 1794. (2751 cases.)



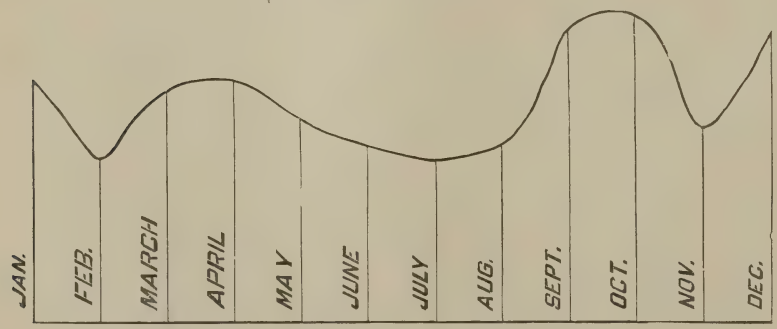
No. 3. From 1794 to 1843. (2741 cases.)



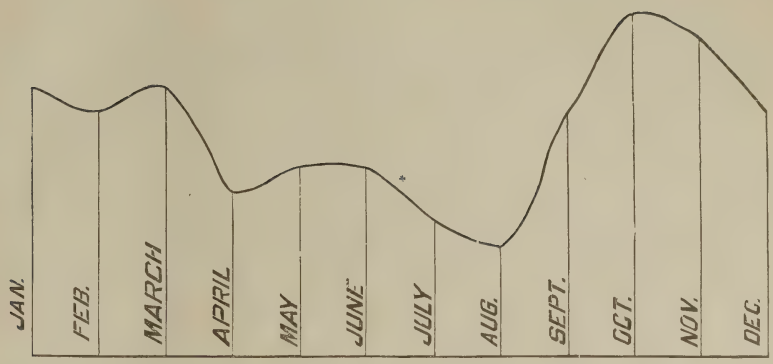
No. 4. From 1862 to 1877. (474 cases.)
Southern Hemisphere.



No. 5. 3299 cases in Europe.



No. 6. Pacific Coast—1850 to 1887. (768 cases.)



No. 7. San Francisco—1850 to 1887. (254 cases.)

ERRATTA.

Correction page 7, line 8 :—But, although the intensity of the wave decreases, the horizontal component of the earth-motion will at first increase, and there must be at some distance from the center, etc., etc.

TECHNICAL SOCIETY OF THE PACIFIC COAST.

INSTITUTED APRIL, 1884.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

(VOLUME VI.—MAY, 1889.)

THE ELEMENT OF LABOR IN ENGINEERING ESTIMATES.

BY J. RICHARDS, Mem. Tech. Soc.

[Read April 4, 1889.]

In all kinds of engineering work and skilled manufactures the elements of prime cost follow some kind of regular proportion, consisting primarily of three components—Material, Labor and Expense. I do not include profits, risk, danger and so on, because these are variable quantities, not appearing in estimates and accounts.

In manufactures of the mechanical class, the proportion of labor-cost or wages charged up to product constitutes, on an average, four-tenths. In engineering work it is less, because of the greater amount of material used, and does not, I presume, exceed three-tenths. Assuming this, labor becomes the second element and, for many reasons, the most important one; yet, it happens that, with a few exceptions, we have no generalization respecting this component — no treatment of it as a thing that may be analyzed, estimated and compared.

It is the purpose of my paper this evening to make some attempt to deal with this subject. It will be done imperfectly,

no doubt, because data is wanting, and my remarks will have to be confined almost exclusively to personal experience and observation. The views presented will be to suggest investigation on the part of the members, rather than to exhaust, or even compass, the subject.

Of investigation into the subject of labor we have enough. Thirteen States have, at this time, "Bureaus of Labor" for the preparation and compilation of statistics. In 1876 the U. S. Treasury Department at Washington issued a public document of 850 pages, under the title of "Labor in Europe," compiled by Mr. Edward D. Young, and known as "Young's Labor Statistics." In 1885 there was printed by the Department of State a document of 193 pages, under the title of "Labor in Europe." There are other publications on the subject, including the reports of Secretary Evarts, 1889, and Secretary Blaine, 1881, but those referred to are enough to indicate the line of investigation pursued. We have also a National Bureau of Labor Statistics, created by an Act of Congress, charged with "collecting information upon the subject of labor, its relation to capital, the hours of labor and the earnings of laboring men and women, and the means of promoting their material, social, intellectual, and moral prosperity." I am quoting from the Act of June, 1884.

The State reports, a number of which I have examined, are voluminous and complete in so far as the ground covered and the whole amount of matter printed each year under the head of "Labor Statistics," State and National, will not fall short of 5,000 pages, and yet, in all this vast amount of matter, I have been able to find no data, and I may say almost no mention, of the main thing of all—the amount of labor and wages entering into the cost of commodities, or the producing power of labor. The *rate* of wages is treated exhaustively, the *amount* of wages is scarcely mentioned. The "rate" of wages and the "amount" of wages are two very different things; the rate is more a social question but the amount is an economical one, and is that one which engineers and manufacturers are called upon to deal with continually. In making up an estimate, for example, the rate of wages would form no clue to the cost of this element, except

by analogy, and I will venture to claim that in all this mass of printed matter that has been named, there is not sufficient information to warrant an engineer or manufacturer in reading over the titles alone. We have in "Young's Labor Statistics" more than 50 pages devoted to the degraded slave labor of ancient Egypt, and among the Jews, and Romans, that is little more than an insult to modern skilled industry, and reminds one of the writings of some French economist who classes thieving, prostitution, and labor in the same category. Of the main subject, the true economic one, of the cost and amount of labor as an element of production, we have as before said nothing.

This it may be claimed is an engineering view of the matter and that the purpose of investigation is moral instead of industrial and technical. This we cannot admit. The Act of Congress creating a National Bureau points clearly to economical as well as moral objects, besides, how easy it would be, while investigating other things to have ascertained the relation that wages bear to production, and the rules that govern labor cost in making up estimates.

Every set of manufacturing or engineering account books show this; there is always a wages account in making up prime cost, and with the slightest additional labor we might know the cost of excavating and moving a cubic yard of material, the cost of leveling, surveying or other engineering work—of building a house, a ship, wagon or locomotive. There was nothing to do but to subtract material and expense and then divide product into the labor account.

A circumstance happening in 1877, caused me to suspect the existence of some general law governing the rate of wages in skilled industries. I was called upon to design for the Royal Arsenal in St. Petersburg, Russia, some special machinery to be employed in making the wheels of gun carriages. The designs occupied about one year's time, and when approved came the question of construction. Estimates made in this country and in Europe varied some, but not a great deal, and the labor or wages item was uniform, or nearly the same, in these cases, where the *rate* of wages varied a great deal. It seemed strange at first that estimates should be so uniform, but on more reflec-

tion it became obvious that the finished or completed value of any kind of skilled product *must* be near the same in all countries; otherwise, there could be no international trade in such commodities; they would center to the place of cheapest production. Greatly interested in the matter and believing I had discovered or discerned a general law or rule applying to skilled industry as an element in production, I wrote to the Hon. John Bright, asking whether he was aware of any principle or rule applying generally to skilled labor and the relation between the rate and the amount of wages. His answer indicated that he had not, and subsequent investigation proved that among writers on the subject, with an exception or two hereafter mentioned, no one had traced the relation between wages and product. This circumstance was the beginning of a course of observation, the result of which forms the main part of the present paper.

In the United States, at different places, are made large numbers of watches of good quality. These watches, many of them, are exported abroad and sold in competition with the Geneva trade. The Waltham Company has an agency in London, and sell there a great many watches. Now, the wages paid in the Waltham Works, to first-class mechanics, exceeds $4 per day. Women receive as high as $2.75 a day, and the average of wages paid is about five to ten times as high in rate as are earned in Geneva; yet, the amount of labor in the watches must be a good deal less in this country, because of the expense of selling them abroad, and also because all material, except gold and silver, cost a good deal more here. The expenses are also greater, and the problem arises, how is this done? We all know it is a result of skill and machinery, both of which are emanations from skilled workmen. But the point I wish to draw attention to is that the amount of labor or wages charged against a Waltham watch cannot be more than two-thirds, and perhaps one-half, as much as for a Geneva one of the same grade; so the cost of finished production is balanced, the aggregate of components coming out the same, no matter how they may vary relatively.

In 1877 my firm was called upon to construct some machinery

for a coffee plantation on the island of Ceylon, in the Indian Ocean. With the things required was a plant for making packing-boxes from the native timber, and among the machines was a saw-bench intended for slitting up small logs, or balks, into boards. The planter was asked if he wanted a feeding attachment on the machine, such as is common in England. "No," said he; "it requires seven men to work the saw, and they can feed by hand." Two men mounted and fed the timber, one took from the saw, and one piled away. There was an "engineer" to oil the machine and file the saw, one attendant to bring water and run errands, and a "boss" over all. The wages paid were from 9 to 12 cents a day. I asked the planter what amount of timber was sawn in a day, and his answer was, "about one-half as much as one man would saw here on the same machine."

Supposing the statement correct, the ratio of production was 14 to 1 in favor of Caucasian labor, and the amount of wages paid for sawing a given amount of boards was actually a good deal more. under the low rate of wages paid in Ceylon.

Some time ago, when waiting for a train on the Southern Pacific Railway Company's line in the San Joaquin valley, I noticed the station agent harassed by his duties, and awaiting an opportunity, ascertained he was freight agent, passenger agent, express agent, telegraph operator, and perhaps performed other duties. His multifarious occupation earned $80 per month. I ascertained roughly the amount of freight shipped and received, and the quantity of other traffic; and comparing with a station on the London & Northwestern system in England, concluded that six men would be employed there to perform the same work. I connected this with the recent estimates showing a lower cost per "ton mile" for moving freight in this country, and in the circumstance detected another proof of the principle of balanced labor cost, independent of its rate.

There appeared, some time ago, in one of our daily papers, the particulars of some house carpenter work done in Yokohama, Japan, for an American resident there, but have failed to find an extract made at the time. The conclusion, however, was that the same work performed here by men at $3 or even $4 a

day would have been much cheaper than in Yokohama at 30 to 40 cents a day, and I do not doubt it.

In some carefully made investigations during the past year into the cost of manufacturing boots and shoes in four European cities, two in England and two in Germany, showed a strange variation in the components of cost. The most marked was in comparing Vienna, Austria, with Lynn, Massachusetts, the ratios being in definite mathematical relation. The *rate* of wages earned in Vienna was one-half as much as in Lynn, and the *amount* of wages was double in Vienna; in other words, the product of American workmen was four times as much as that of the German workmen. The investigation extended to every particular, even to sewing on buttons. It can be found in our consular reports. I do not know how nearly balanced the value of the finished product was in the two cases, but the difference could not in any event be more than the cost of carriage between Lynn and Vienna.

I have for many years been in position to know the labor cost of various machines made here and in Europe from the same drawings; also, other items of prime cost, and find in all cases the finished cost of almost any kind of machinery, including skilled labor, is not much different in this country and elsewhere. The aggregate of the three components, labor, expense and material is much the same, labor being more constant and uniform than either of the other elements.

The wages of Chinese laborers on the Pacific Coast is about one-half as much as is paid to white men, and I have no doubt bears a very constant relation to what they perform; in fact, must do so in cases where the labor cost for a specific work is ascertainable.

There is on the Pacific Coast especial opportunities for observing the relations between the rate and the amount of wages. Many of our prominent engineers have had experience in the labor of Mexico, Central and South America, and have to carry into estimates labor at various rates, and it is expected that this paper will be supplemented with a good deal of information from members of the Society.

The California Combined Harvesting machines cut from 12 to

24 feet wide, 30 to 50 acres a day, and are operated by either four or five men. The grain harvested, cleaned and sacked, is from 300 to 400 bushels for each man employed, and the cost per acre, about 75 cents. The horses and machinery, divided by product, cost less than in the Eastern States, that is, the low labor cost is not compensated by mere machinery and animal power, but rather the reverse.

The cost per bushel, in wages, for cutting, thrashing and sacking is from 5-10 to 7-10 of a cent, and is no doubt much less than in Eastern and Northern Europe or in Asia, and is certainly not a half as much as in our own country, east of the Alleghany mountains.

It is, I think, an example showing how useless it is to pit low priced manual effort against high paid skill and energy.

I might go on, if time permitted, to give examples without number to prove a general law governing the amount of labor entering into constructive work, but will confine myself to one more illustration, the most important perhaps that can be named because the most comprehensive,—the experience of Sir Thomas Brassey, the great railway contractor.

He was engaged for a period of 37 years in constructing railways in all parts of the civilized world, in Russia, England, Germany and France, also in India, Australia and Canada. He had under his employ at times as many as 5000 men, from skilled engineers down to the common navvy.

Laborers' wages varied from 8 cents a day in Hindostan to $1.75 a day in Canada and Australia, and it is doubtful if any firm or company ever had before, or ever will have again, such an opportunity of drawing general conclusions respecting the relation between the rate and the amount of wages.

The work performed was of nearly uniform character, the means and implements employed were quite the same, but the labor rate, as before named, varied between extremes as 22 to 1. In France the labor rate for Frenchmen was, at first, one-half as much as was paid to Englishmen; but in a year or so from the time of commencing it was found the French workmen could perform as much work as the Englishmen, and as a significant circumstance their rate of pay rose in the same proportion.

Mr. Brassey found it expedient to take out English navvys to India at five shillings a day, including the time of transporting them, and furnish "beef and beer," rather than employ the natives at one-tenth the rate per diem.

At the end of this long and remarkable career, Mr. Brassey's conclusions were that labor was the only constant or uniform element he had to deal with in his estimates, and was nearly uniform irrespective of varying rates

It is to be regretted that the great amount of data collected by Mr. Brassey has not been more carefully collected and preserved for the use of engineers. The facts here given are taken mainly from a book called "The Life and Labors of Sir Thomas Brassey," from which some notes were made several years ago.

In this connection may be mentioned some elements entering into estimates and cost accounts familiar to all here, but seldom understood by unskilled people. These elements are the time required for completing a work as affected by the proficiency of labor; the cost of superintendence as affected by that time; the wear and destruction of implements, also the expense of housing, feeding and hospital care, such as was necessary in the work at Panama. All these elements have to be multiplied into the number of men, the number of men being first divided by their skill. It is a kind of equation that every engineer has to deal with in his practice.

Mr. Hawkshaw, another eminent English engineer, now living, who has employed labor in various parts of the world, came to the same conclusion as Mr. Brassey, that the *rate* of wages is a resultant of their product, and that this element of labor in engineering work is the one most easily dealt with because the most uniform, and when there is no extra adventitious circumstance, such as climatic dangers from heat, cold, or disease, the amount of wages to move a yard of earth or stone, or to build a perch of masonry, would be much the same whether the rate of pay be high or low, or to put it in other words, the rate always adjusts itself to product in obedience to an economic law that maintains uniform, or nearly uniform, values for engineering work and skilled industry in all parts of the world.

This brings me to the propositions, or rather to the inferences

to be drawn from the circumstances dealt with and observed, and I will embody them in some postulates as follows:

First.—The component elements of all skilled productions are labor, material and expense. This proposition is no more than an axiom because every set of engineering or manufacturing account books will show its truth. So will every estimate for work. I do not include profits, because that is an independent element without any fixed relation to the others, although it may greatly modify them.

Second.—The prime cost or finished value of whatever is produced from these three elements has, in the markets of the world, an uniform, or nearly uniform, value, the "world's" value it may be called. For example, steel, iron, copper, leather, locomotives, guns, machinery, ships, and so on, can not vary much in price in different countries; otherwise, all trade would center in the cheapest place. In staple commodities, such as cotton, cloth, iron, and so on, it is claimed that five per cent. is enough to control neutral markets.

Third.—The value of finished products being thus fixed, it follows that their components must also be fixed, that is, the aggregate of components or elements, must be the same, and this we will find to be true irrespective of the variations, not only of the rate of labor, but also its amount. If the element of material is increased either wages or expense must be decreased accordingly. If wages and expense are increased, then material must be diminished in the same degree. The balance must be maintained.

If these propositions are granted, then we have the following inferences, or, as I might almost say, facts, resulting:

First.—That wages, the world over, are nearly uniform, if measured by their product.

Second.—The *rate* is a direct result of product, and a simple exchange of equivalent values.

Third.—That fluctuations of the labor rate may arise from

supply and demand, strikes, or other disturbing causes, but the general rate is amenable to the great law named.

Fourth.—And most important of all, that any industry where the aggregate of these components exceed the world's value, must, sooner or later, perish and cease.

Of this inference we have here in California ample illustration. I am told that in former times, when wages were governed by what men could earn in placer mining, and rose to two or three times the general or national rate, no industry was possible except what related to mining, and the product of which, was consumed by miners. Even garden products were not grown; and as to making anything to be sold elsewhere, such a thing was not thought of.

I will now revert to another connected matter, respecting which I have not much data — one forming a corollary to some of the propositions named, and one that will come within the province of many of the members here to observe; it is this: Not only does the rate of wages seem to be governed by production, but the higher rates lead to the cheapest production. This seems anomalous, and the fact is deserving of careful attention. In the instances named I have attempted to show a balance of labor, but as a matter of fact, the ratio between rate and amount seems to be in favor of the higher rate. I mean normal rate, or general rate, and not a forced one such as we know a good deal of on the Pacific Coast.

The primary causes of a high "rate" and a low "amount" of wages I will not attempt to deal with in the present paper. This would involve social and economic problems lying without the field prescribed for papers read before the society, and I have endeavored to confine the remarks to the curious, or at least unconsidered laws that govern labor cost as an element in skilled production.

It is suggested that some concerted action of this and other societies of the kind would, no doubt, influence the National and State Labor Bureaus to include in their future statistics, the amount as well as the rate of wages, so the components of production would appear. This was done in a few cases in the

Michigan reports of last year, but only a few, and evidently without any plan of including it as a part of the system.

The practical value of this method would appear in a better understanding of the conditions attending on successful works and manufactures. Workmen would not strike for unreasonable wages if they were shown that the components of production cannot be increased collectively without driving out or destroying an industry, and that the amount of wages cannot be more or less except as measured by what they produce, and cannot be more in one place than in another except as the other components, material and expense are increased and diminished accordingly.

In conclusion, I will suggest that the whole problem can no doubt be resolved into an equation in which the elements would be as follows : the number of workmen ; the efficiency of workmen ; the rate of wages, the amount of wages ; the value of product, and so on. Looking over the whole field of human knowledge we find scarcely anything known or proved until it is put upon a mathematical basis, and it may be left for this society to solve some of the economic problems of our day by resolving them into an equation.

I seriously believe that no other solution of these problems is possible. An age of wrangling and empirical opinion has proved other methods of no use.

TECHNICAL SOCIETY OF THE PACIFIC COAST.

INSTITUTED APRIL, 1884.

PROCEEDINGS.

(VOLUME VI.—No. 1.—1889.

MINUTES OF MEETINGS.

REGULAR MEETING.

January 5, 1889.

President Manson in the Chair.

The nominating committee appointed at the December meeting presented the following list of officers for the ensuing year:

President—Marsden Manson.

Vice President—E. J. Molera.

Secretary—N. S. Keith.

Treasurer—E. L. Ransome.

Directors—G. W. Percy, G. F. Allardt, W. G. Raymond, Luther Wagoner, Arthur F. Price.

Mr. Molera moved that a number of volumes of the Transactions of the Society be bound and distributed at the judgment of the Executive Committee. Adopted.

Mr. Keith suggested the advisability of discussing, at some future meeting, the subject of Windmills; and it was decided to request the President to appoint a committee of three mechanical engineers, and himself, to take preliminary steps in the matter.

Adjourned.

ANNUAL MEETING.

January 25, 1889.

President Manson in the Chair.

Messrs. Weber and Behr, the tellers appointed to count the ballots, reported that 22 votes had been cast, and that each of the candidates received an equal number of votes.

The following gentlemen were accordingly declared elected:

President—Marsden Manson.

Vice President—E. J. Molera.

Secretary—N. S. Keith.

Treasurer—E. L. Ransome.

Directors—G. W. Percy, G. F. Allardt, W. G. Raymond, Luther Wagoner, Arthur F. Price.

After a vote of thanks to the President, the retiring Secretary, and the tellers, the Society adjourned.

REGULAR MEETING.

February 1, 1889.

President Manson in the Chair.

Owing to the absence of Mr. Von Geldern, his paper on "Falb's Theory of Earthquakes," was deferred till the next meeting.

President Manson described the effects of Sewage from the United States Mint in San Francisco, upon the materials of the old sewer; and the means taken to avoid their repetition in the new.

Mr. Keith called the attention of the Society to the organization of the California Electrical Society.

Mr. Gutzkow suggested sulphur as a protective lining for the sewer of the Mint, it being resistant to the acid liquors running in the sewer.

Adjourned.

ADJOURNED REGULAR MEETING.

March 8, 1889.

President Manson in the Chair.

Mr. Otto von Geldern read a paper entitled "Falb's Theory of Earthquakes.

Adjourned.

REGULAR MEETING.

April 5, 1889.

President Manson in the Chair.

The Secretary read Mr. John Richards' paper entitled "The Element of Labor in Engineering Estimates."

The paper caused considerable discussion, which was carried on by the President, Mr. Dickie, and Mr. Keith.

Adjourned.

TECHNICAL SOCIETY OF THE PACIFIC COAST.

INSTITUTED APRIL, 1884.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

(VOLUME VI—JUNE 1889.)

ECONOMIC HEAD FOR LONG PIPES.

BY ROSS E. BROWNE, MEM. TECH. SOC.

Read June 7, 1889.

The subject matter of this paper is intended to apply mainly to wrought iron pipes of large diameter, having tapered inlet and free outlet, and designed for the delivery of a considerable volume of water, and not for the development of power.

In a general way it may be said that the costs of such pipes, of the same make, are approximately proportional to their weights, *i. e.*, to the products of their lengths, diameters and the thicknesses of iron used in their manufacture.

Let H	be the difference of level between inlet and outlet.
L	" the length of the pipe.
D	" the diameter.
t	" the thickness of the iron.
λ	" Weisbach's coefficient of friction.
Q	" the volume of water delivered per unit of time.
*k	" the cost of the pipe per unit of length at any point.
*K	" the total cost of the pipe.

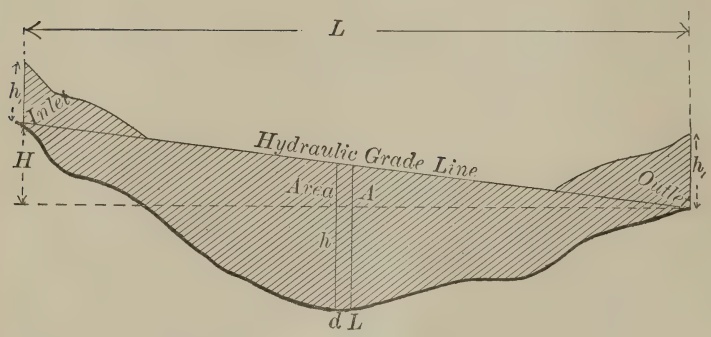
* The cost of transportation and distribution of the pipe may be added where these are proportional to the weight, but the cost of preparing the bed for laying the pipe is not considered.

c_1, c_2, c_3, c_4, c_5 " constant coefficients.

†h_1 " the head corresponding to the least thickness of iron which it is practicable to use.

A " the area between the hydraulic grade line and the approximate profile of the pipe line + the additional area due to h_1.

h " the head governing the thickness of the iron at any point. This represents the variable ordinate of the area A.



The diameter of the pipe is assumed to be uniform, and the thicknesses of iron proportional to the values of *h*. The fact that the latter condition can only be approximated will not materially affect the conclusions reached.

$$t = c_1 Dh \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)\ **$$

$$k = c_2 Dt = c_3 D^2 h \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$K = c_3 D^2 \int_0^L h dL = c_3 D^2 A \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Equation (3) may be used in making a preliminary estimate of the cost of the pipe; but as the stated object of the pipe line is

† With diameters from say 1½ to 5 feet, such minimum thickness may be regarded as approximately proportional to the diameters. In general $t = c_1 Dh$, and we may consider h_1 as constant within the limits of diameter named.

** For double-riveted sheet iron pipe, such as commonly used on the Pacific Coast, $c_1 = .000016$ to $.000024$ for unit of dimensions 1 foot.

the delivery of a fixed volume of water, in order to reach a criterion of economy the cost must be expressed in terms of Q.

In applying Weisbach's formula $Q=\frac{\pi D^2}{4}\sqrt{\frac{2gH}{1+\lambda\frac{L}{D}}}$ ..... (4)

to pipe lines of any considerable length, the value of $\lambda\frac{L}{D}$ is so great that the 1 may be neglected without serious error, and by transformation $D=c_4\ Q^{2\cdot5}\left(\frac{L}{H}\right)^{1\cdot5}$ .....*(5).

Introducing this value of D for the delivery of a given volume of water, into equation (3) we obtain

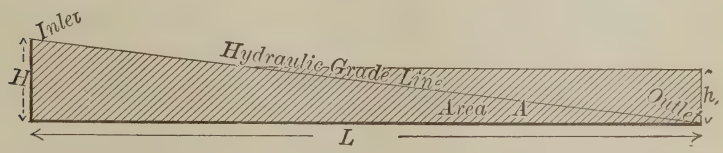
$$K=c_5Q^{4\cdot5}\left(\frac{L}{H}\right)^{2\cdot5}A \text{ ..... } (6)$$

It is apparent that the cost of the pipe for the delivery of a given volume of water is measured by the quantity $A\left(\frac{L}{H}\right)^{2\cdot5}$, and the smaller this quantity can be made, the less the cost.

It is not uncommon to meet with cases where the head, H, is unnecessarily great, and where it is a matter of economy to carry the water a part of the way from the source of supply in ditches or flumes, or even in light pipe broken at intervals to avoid the necessity of using heavy iron.

In estimating the cost of a very long pipe, I was somewhat surprised to find how low was the most economic head, H, governing the proper location of the inlet of the pipe.

In the following example there is assumed an abrupt slope and a long plane, such that the head, H, may be varied without materially affecting the length.



* λ varies with D and velocity, but may be taken for the purpose of preliminary estimate as having a constant value, say=.02, $D=.22Q^{2\cdot5}\left(\frac{L}{H}\right)^{1\cdot5}$ for unit of dimensions 1 foot, unit of time 1 second. It is not the purpose of the present paper to discuss the values of coefficients c_2, c_3 and c_5.

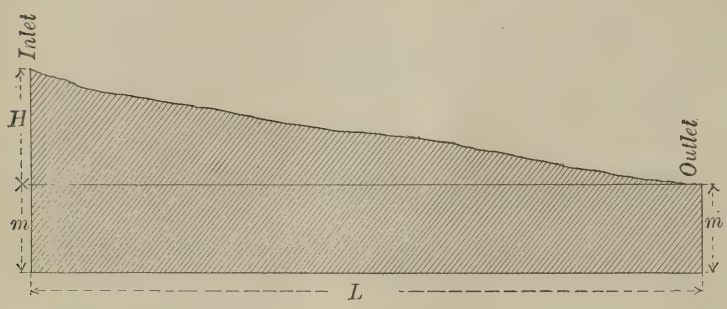
In this case $A=\frac{L}{2}\left(\frac{H^2+h_1^2}{H}\right)$ hence $K=\frac{c_5 Q^{4\cdot5} L^{7\cdot5}}{2}\left(\frac{H^2+h_1^2}{H^{7\cdot5}}\right)$

see equation (6). And this value of K is a minimum for $H=h_1\sqrt{2\frac{1}{3}}$.

Or it may be said the cost of the pipe is approximately a minimum for $H=\frac{3}{2}h_1$.

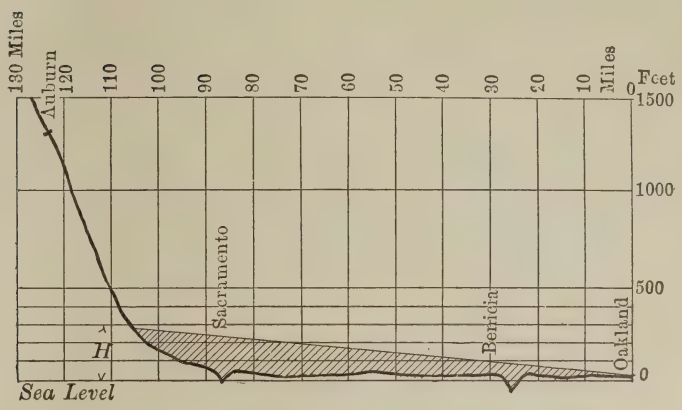
For double riveted sheet iron pipes having diameters between $1\frac{1}{2}$ and 5 feet, if the mean value of $c_1=.00002$ is used, the value $h_1=165$ feet, may be adopted. The cost, then, in the above case will be a minimum for H=250 feet, and this approximates the truth, whether the length of the pipe be 1 mile or 100 miles.

In the following example there is assumed an abrupt fall from the inlet, a long plane, and an abrupt rise to the outlet.



In this case $A=\frac{L}{2}(H+2m)$, and K becomes a minimum for $H=\frac{4m}{3}$. If m is less than h_1 this result will be modified.

These cases may be applied to the Sierra Nevada water supplies formerly proposed for the cities surrounding the bay of San Francisco. The profile of a possible pipe line through Sacramento, Benicia, San Pablo, to Oakland, is about as follows:



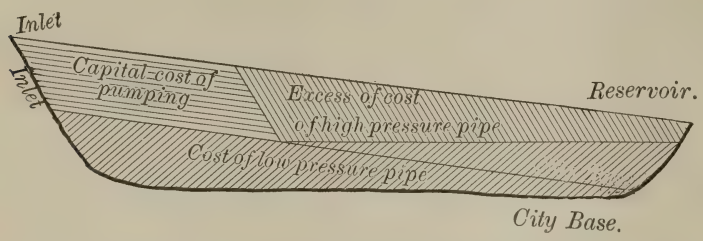
Owing to the fact that by decreasing H the length of the pipe is somewhat decreased, it is apparent that the most economical head, H, is liable to be even less than 250 feet.

This applies to the delivery of the water at the city base. A simple calulation will show that with so long a pipe line (100 miles or more) there is no economy in attempting to deliver the water under such pressure as is required for the city service. A large saving is effected by delivering the water at or near the city base, and then pumping it to the city service reservoir.

If, for example, there is considered the supply of 10,000,000 gallons of water daily from the Sierras to a reservoir back of Oakland, having an altitude 200 feet above the city base, the cost of delivery under the system of high pressure will exceed, by a million and a half dollars or more, the cost of delivery to the city base + the capital represented by the annual cost of pumping.

This is illustrated graphically in the following diagram—the

areas representing cost — the total area the cost of the high pressure pipe:



In the estimate, upon which the diagram is based, the price of the pipe was obtained from a large manufacturing firm.

If the length of the pipe were only 30 or 40 miles there would be required a more careful estimate to determine the choice between the two systems.

TECHNICAL SOCIETY OF THE PACIFIC COAST.

INSTITUTED APRIL, 1884.

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(VOLUME VI.—NOVEMBER, 1889.)

NOTES ON THE BEET SUGAR INDUSTRY IN CALIFORNIA.

BY E. C. BURR, MEM. TECH. SOC. PAC. COAST.

[Read September Meeting, 1889.]

At a time when the Beet Sugar Industry is attracting general notice, it may not be amiss to call attention to some of the points which must be considered to make it a complete success.

It is of first importance to find out the quality of soil which will produce good beets, that is, beets containing over twelve per cent. of sugar, with a high coefficient of purity, and of a size to repay the farmer for raising them.

An analysis of a soil will give no idea of its capabilities. The only test is to plant *proper* seed in a *proper* manner, and examine the resulting beets.

In addition, the physical qualities of the soil should be observed, for, although beets will grow on adobe soil and clayey lands, it will be found that the cost of digging is too excessive for profit. The beet will also have a tendency to grow out of ground, showing that the soil has been too rigid to allow development. A rich, loose, friable soil of a sedimentary nature, is the one best suited for sugar beets. Sown in early spring, when

the earth is in a mellow state, which allows of its almost complete pulverization, deepest plowing and perfect preparation, the beets show their leaves above the ground within a week or ten days. Should a rain occur immediately after seeding, sufficient to cake the soil, a large percentage of the seed will fail for lack of power to force its way through the crust.

As soon as three leaves have formed, or when the rootlet is the size of a slate pencil, it is time to begin the thinning out and weeding. This requires much labor and time, for the plants are rapid growers. Before the whole acreage, tributary to a factory, has been gone over, the roots will have increased marvelously in size. The longer the time in thinning out, the more detrimental it is to the plant's growth, as it is almost impossible to remove superfluous plants without more or less disturbing the one that is to remain.

Hardly is the thinning over than it is time to kill the weeds, which for a second time threaten to choke the roots. This weeding over, the plants will take care of themselves, and soon shade the ground with their broad leaves.

In Europe, a third weeding is often necessary, but our dry climate, which later on may cause doubt and anxiety, saves us the expense, and to this extent is beneficial.

Stammer, the standard writer on Beets and Beet Sugar, says that they delight in the strong sunshine, although sometimes there may be too much of it.

In California there is but little moisture in the sky from April to October. Unless the earth has been thoroughly saturated by timely rains in winter and spring, there may be fears of drought with its subsequent curtailment of the yield. With all its advantages of a long tap root the beet suffers, and after attaining half its growth ceases to progress, and soon shows unmistakably the lack of water. The leaves begin to wilt, then shrivel up and dry. The root, indeed, does not at once lose in sugar, but on the contrary, shows a rapid increase in polarization, while the quotient of purity remains unchanged. Weekly examinations of the plants show a decrease in weight, first of the leaves then of the roots. The relations of the solid matter remain unchanged, but the specific gravity grows higher each day.

It has been stated to the writer, on good authority, that the eminent statistician Licht, in Magdeburg, denies the possibility of beets ever containing over sixteen per cent. of sugar on an average. But it is a fact that the beets raised this year, at and around Alvarado, contain an average of *twenty per cent.*, and on one farm near Centerville the average is as high as *twenty-three per cent.*

It is not, however, a subject of congratulation. On the contrary, it means abnormal dryness of the soil, with consequent small yield in weight per acre.

As a matter of fact, the juice of the beets maintains the same quotient as when the polarization was lower. Nothing has been taken from the beet but water. Resulting from this, lands which hitherto have yielded twenty tons per acre, will this year do well if they produce ten.

Taking the immense area of the State into consideration, there will always remain a large extent of territory which will annually produce good, fair-sized beets, with an average polarization of about sixteen per cent, and quotient of eighty-five to ninety.

What irrigation will do for the beet cultivation is yet an unsolved problem. However, there seems to be no reason why, by ceasing to irrigate, say about July 1st, the roots should not keep on growing until September.

The Coast counties will undoubtedly retain their moisture in ordinary years, but for the interior ones it will be necessary to adopt some form of irrigation.

There is another danger connected with an excessively mild climate, to which attention must be called, and that is a warm autumn or winter following the harvesting of the beets. When kept in sheds or piles the beets are liable to sprout in this climate, and if they do, a rapid change takes place in the sugar percentage. A few warm days in November will spoil beets rapidly when not kept in a cool place. Happily warm winters, like the one which has passed, are not common within the boundaries of our State.

The only safeguard against this difficulty is cold storage. With a view to determine how long beets can be kept at a low tem-

perature, it has been decided to make the test this year, by placing several tons of ripe beets in the cold storage warehouse in this city, under varying degrees of temperature. If it shall be found possible to keep them for six months, or from October to April, the question of loss by deterioration will have been solved, and, at the same time, it will be possible to extend the manufacturing season to double its present length. Under present circumstances the campaign begins about the latter part of August and lasts until the end of December. During these months the beets must be kept in such a way that the suger contents do not deteriorate. The European method is to preserve the roots in pits covered with earth and straw. As the winter months are cold it costs but little trouble to keep them at a temperature which will prevent fermentation or germination.

Nor must they be allowed to freeze, for during the subsequent thawing a large percentage of roots will spoil.

In California the climate is, as a rule, sufficiently cool to allow of the preservation of the roots. Occasionally, however, we have a season of exceptional mildness, and it is especially against such a one that precautions must be taken. As an instance the past winter may be cited, when, by reason of the unusual temperature in December, over five thousand tons of roots at Alvarâdo had their contents converted from sugar to glucose. At Watsonville, it was reported that the loss was also great.

Of course, if the beets could be taken direct from the ground to the mill the loss would be reduced greatly in amount, but this is not always practicable, as the factory is usually worked up to its maximum capacity, while the deliveries of roots often exceed the abilities of the factory to handle them. Sheds as a protection from the weather are now used, but they hardly serve against warm days. The quantity to store is so large that the outlay for sheds becomes quite an item in the cost of a sugar establishment.

Possibly some method of preservation may be devised to suit the requirements of the climate.

The location of a factory should be carefully considered, for it is a subject which requires much thought. The soil of a district may be adapted to the profitable culture of the sugar beet,

and yet it may be impossible to find a suitable location for the necessary building, where adequate supplies of water, limestone, and cheap fuel may be had. These materials are used in large quantities, and must all be of good quality and cheap.

The water required for even a two hundred ton sugarie amounts to 2,000,000 gallons daily, when the water is used but once and then allowed to run to waste. The amount may be reduced in quantity by using settling ponds and cooling devices; but as these cost nearly as much as the factory itself they are seldom employed even in Europe.

The greater part of the water is used for condensation on the vacuum pans and multiple effects. That which is used for diffusion is about one hundred and thirty per cent. of the weight of beets consumed, and is the next largest item of water supply.

As regards quality, the purer the water the better; an absence of magnesium salts being essential for boilers and diffusion.

Comparatively few localities in California are bountifully supplied with water, and in locating a sugar factory one should rather err in having too much than too little.

As a factory uses so much water, provision must be made for carrying off the waste waters. These cannot be returned to the stream from which they were taken, as they are not only offensive to the smell but also detrimental to animal life. These waters contain a high percentage of potassium salts, together with nitrogenous organic matter.

For fertilizing they are unsurpassed, but they are objectionable on account of the evil odor arising therefrom. Methods of deodorizing, more or less costly, may be adopted to overcome this evil.

The importance of a good and plentiful supply of cheap fuel should not be underrated. The consumption of coal amounts to 22–25 per cent. of the whole weight of beets worked, or say for a two-hundred ton factory fifty tons per day. On a ten per cent. extraction of sugar this would amount to one cent per pound on the sugar manufactured, with coal at eight dollars per ton, a very large item where the total cost of sugar must not exceed three cents.

Petroleum will, in some localities, take the place of coal for fuel, but at present the supply is insufficient to meet the demand.

In the matter of limestone, it may be said that the purest quality is required, both as a matter of economy and as a reagent in manufacture. It does not pay to use a poor rock, when it requires as much fuel to burn it as to burn good. And in the defecation it requires more time to saturate with poor gas than with rich. The presence of magnesia is prejudicial, as many of its salts are soluble.

Large quantities of lime are required for defecation, amounting with sour beets to as much as four per cent. of the weight of beets used. The sources of limestone in this State are common enough, but they are not always of a sufficiently pure quality for sugarie uses. The supply of good rock is plentiful enough, however, for all factories which may be built, and no mistake should be made in this respect.

It is almost superfluous to call attention to the matter of transportation as a factor in locating a factory, but this item is by no means small, and a high freight rate will eat largely into the profits. Few factories will handle less than twenty thousand tons of all products and supplies, even without taking the beets into account. Water transportation is not always to be had, but undoubtedly those factories which locate on great water ways will have a great advantage in the development of this industry.

To what limit per ton a factory can go in its freight expenditures, it is, of course, impossible to foretell, but for those factories which may turn out refined sugars in localities distant from the refining centres, a high rate will prove advantageous, provided raw materials can be delivered at the sugarie for small cost.

The question of a sufficient supply of good and profitable labor is one which, in time, will solve itself At present it is difficult to get a sufficient amount of good labor. The necessities of the industry, from seed time to harvest, require a small army for their supply. The thinning and weeding admit of no delay, and for about two months, after the beets are up, the demand for labor is constant. The work of itself requires no great amount of strength, but the stooping posture in thin-

ning out is very tiresome, and few white laborers like it. The Chinese seem to be fitted by nature for the business, and after once learning what is wanted can do the work satisfactorily. It is better to let it out by contract at so much per ton for cultivation, topping and loading, with an advance when the weeding is complete, rather than to pay by the day, or per acre. If paid by the day constant watching is required; if by the acre they thin out too much, and the yield will be small; by the ton, the object will be to get the largest amount possible per acre. Children may be employed, but their labor is uncertain.

As the factory is only in operation for about four months, and that, too, in fall and winter, it is easy to get sufficient labor, the only difficulty being that each season sees a new crew, entirely unfamiliar with the work. Local labor should be utilized as much as possible, and many will return year after year. As the country becomes more populated, this minor difficulty will become less and less.

The residues of a sugarie consist of pulp, from which sugar has been extracted, and molasses.

The amount of pulp turned out from a two hundred ton factory in a season is very large, and requires immediate removal or storage. The demands for it are small at present, but will increase as soon as farmers discover its value. At present it stands in about the same relative position as do fertilizers. The farmers think they can do without them. For fattening neat cattle or for feeding dairy cows, nothing can be superior. Still its introduction will require time and patience. The pulp should be a source of profit to a factory, and its profitable disposal should be a subject of interest. Its preservation in this climate is open to improvement over the present method of simply piling up and allowing to ferment. Still, the writer has seen pulp two years old in this State, which was at that late date eagerly sought after by milch cows. On examination, after removing an outer layer of a few inches, it was found to be free from unpleasant ordor, and of an agreeable, slightly acid taste.

The beet molasses is not edible, hence unsalable on the market as a syrup. As it is only used for making vinegar, the supply will soon exceed the damand—and then what? It contains too

much sugar to be thrown away, but its profitable extraction is an open question.

The various extraction methods are numerous, and many of them are good. The one question to be solved is that of economy. To extract the sugar alone cannot pay except with high prices ruling. The conversion of the molasses into alcohol and subsequent recovery of the potash salts from the residue, would aid materially in the development of the industry on this coast, but some modification of the internal revenue laws in relation to the tax on alcohol will be first necessary. Alcohol for manufacturing purposes should be free from any internal tax. The English system of adding a certain amount of methylic alcohol, or "wood spirit," to common alcohol, might well be adopted in this country.

In conclusion, although the difficulties in the way of the development of the Beet Sugar Industry are maay, there are none insurmountable. California has many locations where the accessories are to be had without incurring too great expense.

Probably for a few years the pulp and molasses will return no profit, but the time will come when a demand will arise for all the pulp which can be had, and a method will be suggested for the utilization of the molasses.

For some time to come the labor required for harvesting may be dear and scarce, but that matter will also adjust itself to circumstances.

Factories will be built in the near future with materials of home manufacture, and the operators will be Californians.

TECHNICAL SOCIETY OF THE PACIFIC COAST.

INSTITUTED APRIL, 1884.

PROCEEDINGS.

(VOLUME VI.—No. 2.—1889.

MINUTES OF MEETINGS.

REGULAR MEETING.

Friday, May 3d, 1889.

President Manson in the Chair.

A discussion on the proposed union with the Mechanics' Institute was held.

On motion of Mr. Gutzkow, the Board of Directors was directed to confer with the Mechanics' Institute to determine terms upon which the Society can be admitted to the Institute, and report to the next meeting.

The President appointed Messrs. Bell, Wagoner and Raymond a "Committee on Windmills."

Adjourned.

N. S. KEITH, Sec'y.

REGULAR MEETING.

Friday, June 7th, 1889.

President Manson in the Chair.

Mr. Ross E. Browne's paper, entitled "Economic Head for Long Pipes," was read and discussed.

Adjourned.

N. S. KEITH, Sec'y.

There were no Regular Meetings of the Society in the months of July and August, 1889.

REGULAR MEETING.

Friday, September 5th, 1889.

Vice-President Molera in the Chair.

The Secretary read Mr. E. C. Burr's paper, entitled "Notes on the Beet Sugar Industry of California."

Adjourned.

N. S. Keith, Sec'y.

TECHNICAL SOCIETY OF THE PACIFIC COAST.

INSTITUTED APRIL, 1884.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

(VOLUME VI.—DECEMBER, 1889.)

A GRAPHICAL METHOD FOR ESTIMATING EARTHWORK.

BY WM. G. RAYMOND, Mem. Tech. Soc. P. C.

[Read December Meeting, 1889.]

In a recent text-book on Surveying, by Prof. J. B. Johnson, of Washington University, we find a method given for graphically approximating the volume of earth to be moved in grading an extended surface of irregular outline. The writer does not remember to have seen the method described elsewhere. While attempting recently to apply, from memory, the method above mentioned, there was evolved a somewhat different way, which it is believed possesses certain advantages over that given in the text-book. Both methods are so simple that the writer does not doubt they have been used by others ere this ; but as he has not seen the one used by himself in print, he ventures to present it as a method of computation that for irregular work is rapid and as accurate as any with which he is familiar.

Inasmuch as it is believed that the method given by Prof. Johnson is awkward of application, under certain conditions, that method will be first considered for comparison.

Figure 1 is substantially that used for demonstration in the text-book. The irregular full lines are contour lines drawn for every foot of elevation, and show the conformation of the surface of the ground in a square which it is proposed to grade down to a *plane* surface such that the contour lines of the finished grade shall be the straight full lines drawn diagonally across the square. The figures at the ends of these lines and those written on the natural surface contours are elevations above some assumed datum plane.

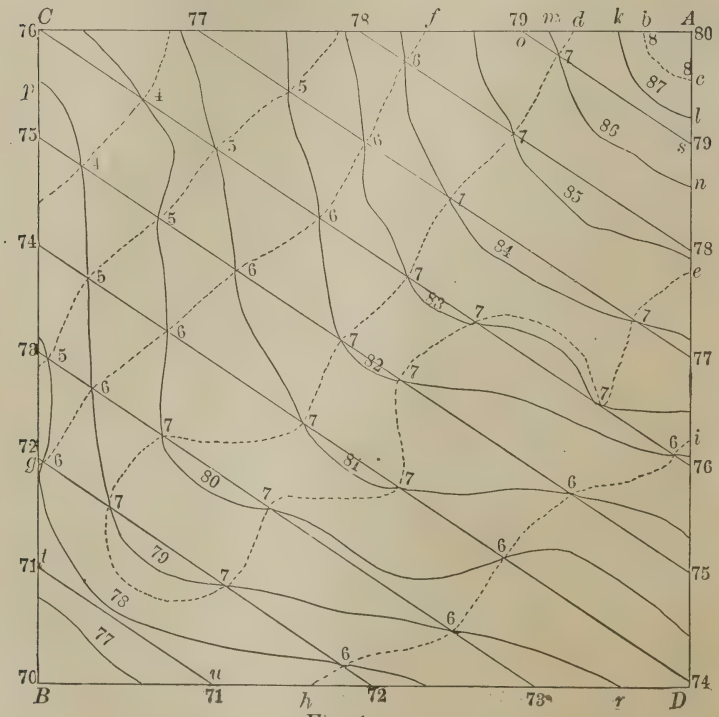

Fig. 1

The sides of the square are to be vertical.

Where a contour of the finished grade crosses a contour of the natural surface, the cut or fill (cut in this case) will be the difference in elevation between the two contours—as for instance,

where the grade contour 78 crosses the natural contour 85. the cut will be 7 feet. By marking all points of intersection with the cut or fill at those points and connecting points of equal cut or fill, we get a series of curves shown by the dotted lines in the figure. These curves are the traces, on the original surface, of planes parallel to the grade plane and uniformly spaced one foot apart *vertically*. The *perpendicular distance* between two adjacent planes is *not one foot*, but something less than one foot. This distance may be obtained graphically by evident construction, or it is known from the rate of grade, taken in a direction perpendicular to the grade contours. Let the *uniform vertical* distance between adjacent planes be *h*. The excavation having vertical sides, the curves of equal cut (in this figure) will all lie partly in the lines forming the sides of the square. The closed area made by each of these curves is the *projected* area in cut in its plane, and these areas may be measured with a planimeter. The area shown in the figure over which the cut will be just 8 feet is the area *A b c A*. That over which the cut is just 7 feet is *A d* 777 *&c. e A*. That over which the cut is just 6 feet is *A f* 666 *&c. g B h* 666 *&c. i A*.

The areas for 1, 2 and 3 feet cut are each the whole square.

These areas being measured they are used as end areas, the common vertical distance between them as length, and the volume computed by the prismoidal formula.

For the quantity between alternate planes, we have, letting A_1 A_2 A_3 &c. be the areas of the planes,

$$V_{1\text{-}3} = \frac{h}{3}\left(A_1 + 4\,A_2 + A_3\right)$$

$$V_{3\text{-}5} = \frac{h}{3}\left(A_3 + 4\,A_4 + A_5\right) \text{ \&c., and}$$

for an even number of *layers* we have in cubic yards—

$$V = \frac{h}{3x27}\left(A_1 + 4\,A_2 + 2\,A_3 + 4\,A_4 + 2\,A_5 + \text{\&c.} \ldots\ldots A_n\right)$$

n being an odd number.

Thus far the method seems to be correct, but we have considered only grading to a *plane*. If the surface to which we are to

grade is a warped or other irregular surface, partly in cut and partly in fill, the writer conceives that the method is not readily applied, as will appear in the consideration of the second case.

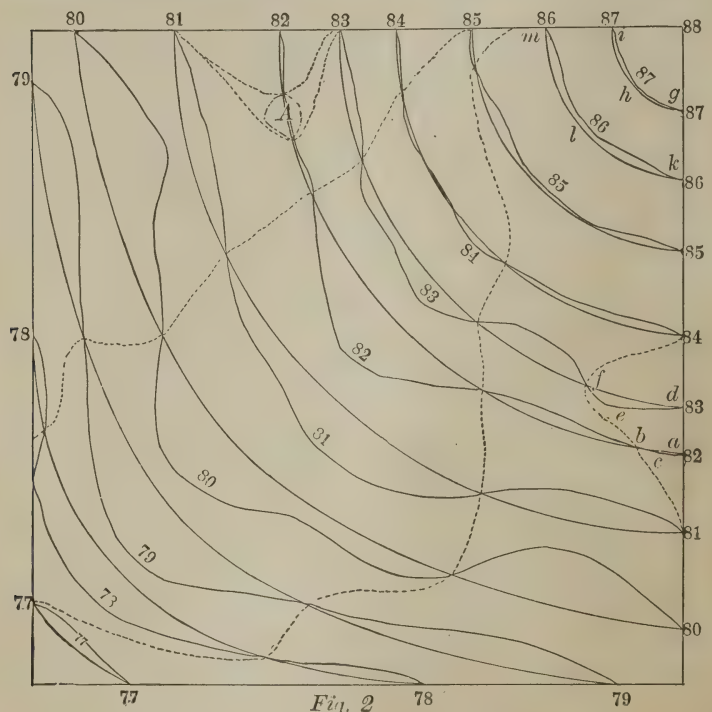

Fig. 2

The method proposed by the writer consists in drawing the natural contours over the area to be improved, and then the contours of the finished grade. The closed figures formed by the intersecting contours of equal elevation are *horizontal* areas of cut or fill separated by the common vertical *and perpendicular* distances between successive contours. These areas may be measured and the computation made by the prismoidal formula, as in the previous method. Where the grade contours do not intersect natural contours of equal elevation, but themselves form closed areas, those areas are to be measured. Taking the figure we have already given, some of the areas of cut would be as follows:

At 87 foot level area A k l A.
" 86 " " " A m n A.
" 79 " " " o C p r D s o.
" 71 " " " t B u t.

Let us now take the same plot of ground and suppose it is required to grade it only to a somewhat more even or smooth surface, preserving practically the same general form, and as nearly as may be the natural elevations on the boundaries. In Figure 2 we have the plot with grade contours shown by the more regular and lighter curves. The dotted lines joining the intersections of contours of the same elevations are lines on the original surface where adjacent cut and fill meet, i. e., "grade lines." In the case of the small cut, near the top of the figure, marked *A*, there are two possible sets of grade lines, as shown. A knowledge of the ground would tell which to use. Some of the areas would be as follows. Beginning with the small piece of cut on the right we have—

At 81 foot level area in cut, nothing.
" 82 " " " " " a c b.
" 83 " " " " " d e f.
" 87 " " " " " nothing.

We next have fill areas as follows:—

At 88 foot level area in fill, nothing.
" 87 " " " " " G h i.
" 86 " " " " " k l m, &c.

The areas being measured the computations are made as before. It is not affirmed that the solids computed are all prismoids, but that the prismoidal formula when applied to them will give results as near the truth as any other method, and as accurate as the construction will warrant.

The method herein presented has given the writer great satisfaction in just such irregular work as that outlined above, and also in computations for regular structures built on irregular ground.

One example will be given :—

A small reservoir is to be built on a hillside, and will be partly

in excavation and partly in embankment. Figure 3 shows such a case. The contours—for the sake of simplicity and brevity—are spaced five feet apart. The top of the wall—shown by the full lines making the square—is ten feet wide and at an elevation of 660 feet. The reservoir is 20 feet deep, with side slopes—both inside and outside—of two to one, making the bottom elevation 640 feet, and 20 feet square, the top being 100 feet

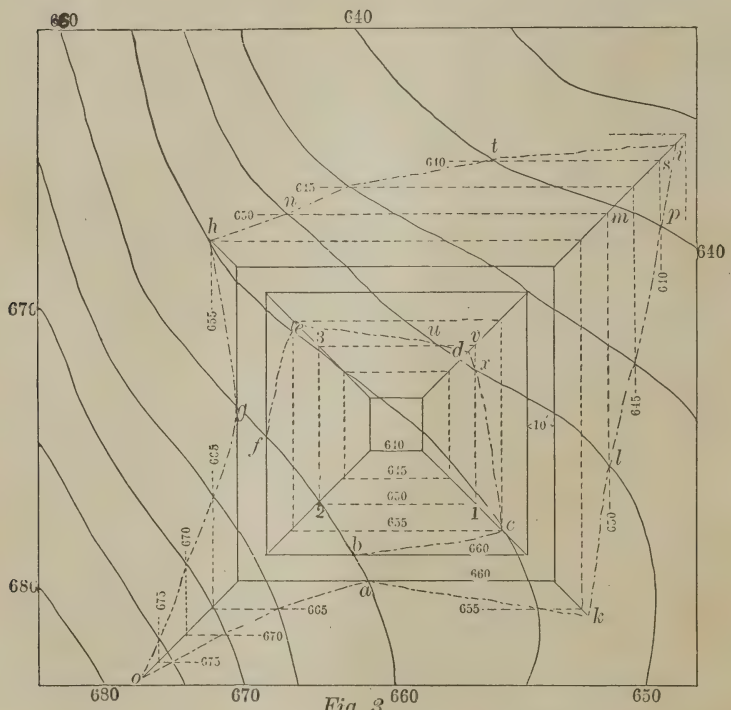

Fig. 3

square on the inside. The dotted lines are contours of the finished slopes, both inside and out, at elevations shown on the figure. The areas in fill all fall within the broken line marked a b c d e f g h i k, and the cut areas all fall within the broken line marked a b c d e f g o. These broken lines are grade lines. The areas of fill and cut are readily traced by

following the closed figures formed by contours of equal elevation, thus—

At 640 foot level area in fill is p s t.
" 650 " " " " " l m n u v x l.
" 650 " " ' " cut is 1 2 3 u x 1.

The other areas are as easily traced. In the figures given the lines have all been drawn in black for economy in printing. In practice they should be drawn in different colors to avoid confusion.

The method thus outlined in this paper might be used in connection with contour maps of railway locations for preliminary estimates, but the writer is not sure that there is anything to be gained by its use in this way. It possesses, perhaps, one small advantage, in that it applies mechanically the curvature correction.

(See p. 163 for [illegible]

TECHNICAL SOCIETY OF THE PACIFIC COAST.

INSTITUTED APRIL, 1884.

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(VOLUME VI.—DECEMBER, 1889.)

ON THE STRAINS IN CURVED MASONRY DAMS.

BY HUBERT VISCHER AND LUTHER WAGONER,

MEMS. TECH. SOC. P. C.

[Read November 1st, 1889.]

EXPLANATORY NOTE.—In this paper, the term *strain* has not been used to designate elastic changes in dimension, as now customary with many writers. *Stress* and *strain* are employed, without distinction, to signify internal forces per unit area.

The object of this paper is to submit to the Society the results of a set of calculations which were made mainly with reference to the Bear Valley Dam. Full plans of this structure were courteously furnished us by Messrs. Black and Chamblin, Civil Engineers, at the request of F. E. Brown the engineer who built the dam, and to whom we had written for data.

The failure of this structure to collapse under the pressure of a full reservoir which it has now borne for five years, augmented at times by the thrust of a sheet of ice two feet in thickness has been a matter of surprise. Tested by theory as commonly applied to masonry dams, failure should have resulted, and its efficiency points—we believe—to the strains being taken up by this dam in some manner other than is usually assumed.

We have been led to a theory which this paper will outline, but which we prefer to offer as an application to an accomplished fact rather than as a purely theoretical deduction.

The Sweetwater Dam,* another interesting structure, but of

*Designed and built in 1888 by Jas. D. Schuyler, Chief Engineer, near National City, San Diego County. For description see Transacts. Amer Soc. Civil Engrs., Vol. XIX, page 201.

far less startling design, which during most of the time of its construction was immediately supervised by one of the writers, has been subjected to partial examination where comparative figures were desired.

A difference of opinion has long existed among engineers as to the extent to which masonry dams built to a circular curve in plan, can offer resistances additional to those which a straight dam of the same cross-section would oppose to its water load.

By some it is taken for granted that the curved structure is free to act as an arch, and capable of transferring all its load through the curve to its abutments; it is maintained by others that no such action can take place, or if it takes place at all, then only to a limited extent hardly worth considering in a design. The result of our calculations leads us to conclude that the latter statement is practically correct; that arch action, as usually understood, adds but little to the strength of a curved dam, notwithstanding which the curved form may to a very marked degree afford additional resistance, and this in a manner less dependent on the radius of the curve than the arch theory implies.

If our explanation proves correct, we believe that the inference to be drawn from our paper will not be without practical value; if it fail under a practical test, we hope that our figures may still preserve some interest and may invite further study in other quarters. Whatever the outcome, we trust to have pointed out the inadequacy of the usually accepted theories to explain the case of the dam at Bear Valley.

Were abridgement not an object, through fear of overstepping the proper limits for a paper, it might not be uninteresting to briefly review the literature which has accumulated upon this subject. French engineers have long considered the question and the "Annales des Ponts et Chaussées" may be referred to for several papers. During the last two years the subject has attracted much attention in this country owing to the proposed construction of the Quaker Bridge dam, which is designed to be 265 feet high from the foundations, the largest dam ever projected. The question of the relative merit of the curved and straight type was discussed in the report to the Croton Aqueduct

Commission, the conclusion arrived at being that, in the case under consideration, a curved dam would require a section about twice as great as that recommended for a straight gravity dam; that is to say, were the dam to act purely as an arch, the application of the ordinary formula for arch pressure ("hoop pressure") would give the above value for the requisite cross-section, provided the strains were not to exceed desirable limits; and the report concluded that, beyond certain widths of cañon (by which the available radii are in a measure determined), the curved type ceased to present any advantages and possessed inherent objections.*

The report attracted considerable notice in the engineering periodicals of the time. That the conclusions did not receive unqualified acceptance may be seen from the very cleverly written review which the editorial columns of the "Engineering News" contained, and also from the final recommendations of the "Board of Experts," who subsequently recommended a curved dam. Attention is also invited to the discussion which Mr. Schuyler's paper on the Sweetwater Dam called forth in the American Society of Civil Engineers,† which discussion is of interest, as it states the views of many well qualified professional men. The present paper has probably found its direct incentive in that debate.

Stated briefly, the point in dispute is about as follows. For narrow gorges the application of the formula for arch pressures may be made to give cross-sections of considerable economy over gravity profiles.‡ The advocates of the curved type seek to utilize this fact, and assuming the capacity of the dam to act as an arch design accordingly. Against this method it has been urged that the conditions for arch action do not exist, and that the fundamental assumption above made is an erroneous one. It is suggested that the curved dam essentially differs from an ordinary arch in the fact that it is rigidly fixed to its founda-

*We shall show that the formula for the arch thrust which led to this conclusion, does not hold good for arches of elastic material.

†See Transactions Amer. Soc. Civ. Engineers, Vol. XIX, No. 398.

‡See Ponts et Chaussées, Vol. 141 (1879), Paper No. 17, by M. Pelletreau.

tions. Now the action of an arch is to resist its load by compressive strains transmitted along its curved lines to the abutments, whereby owing to the compressibility of all material under pressure, a shortening of the length of the arch must result, and owing to this change in length, a change in the form of the arch takes place, all points being pressed inward under the load; hence, a certain freedom of motion is an essential condition for arch action. At the base of the dam this condition cannot exist, and at higher points in the dam it exists only to the extent to which the elasticity of the masonry (in a vertical sense) admits of motion such as arch action requires. Considered thus, the initial strain must be taken up and transmitted to the foundations, and arch action can only play a secondary part, relieving to a greater or less extent the strains which, if the dam were a straight one, would all go to the base of the dam. It would therefore appear merely a question to determine for any given case, what proportion of the load is taken up by the arch.

The opponents to the use of all curvature, however, maintain that the curved dam is a compound system, in which the factor of arch resistance is so indeterminate that good practice precludes its consideration, and that the curved dam should be given a section exactly the same as that for a straight gravity section. From this they conclude that as the curved dam is longer than a straight one, an unnecessary use of material results from the use of the curve, the only offsetting gain being a possible enhancement in architectural effect. In this connection the sacrifice of a so-called "scientific method," the departure from the suppositiously simple strains in the straight type appears a point of much concern to the holders of these views.*

Of the three notable dams with cross-sections smaller than would be accordant with conservative practice for the design of straight dams under like conditions, the Sweetwater Dam† and probably the Zola Dam also, can hardly be drawn on as estab-

*As regards the real simplicity of strains in straight dams, we shall have something further to say later on.

†For cross-section, see sheet 4.

lishing precedents for the auxiliary action of curvature. For, even without any such outside support, they do not warrant the expectation of failure, as they are stable structures against which it can alone be urged that they *may* contain tensile strains in excess of what good practice usually sanctions. Concerning the Bear Valley Dam we regard the case as different. Absolute failure was predicted, and correctly too, provided the strains in curved dams corresponded at all closely to those determinable for straight dams. The design could hardly have been made with less regard to theory, had it specially aimed to serve as a test case ; apart from its startlingly slender dimensions, it spans an arc of only $42\frac{1}{2}$ degrees, and its radius is comparatively speaking very large—say 337 feet to the center of its coping. The dam differs so materially from any previous structure that it cannot fail to be an interesting subject for study ; its successful record may well put our theories to the test.

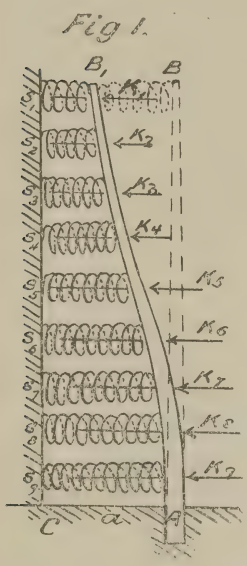
In the discussion of Mr. Schuyler's paper an investigation was proposed, the object of which was to establish the extent to which arch action might enter into the problem. Our first studies were directed to carrying out this calculation, an intelligent application of which encountered difficulties evidently not foreseen by the proposers of the method. The results form the first portion of our paper and are given without any preliminary comment as to the extent to which the method comprehends the full elements of the problem. The suggestion is an outside one, but we hope to have applied it fairly.

FIRST METHOD OF TREATMENT.

Consideration of the Curved Dam as a System of Elastic Vertical Beams, Relieved by Spring Compression (Involute Hypothesis).

The proposition is to imagine the dam sliced up by vertical radial planes into separate beams of unit width, and to determine the deflection which each such beam would sustain under its portion of the external load, if it were imagined to rest on a layer of springs so adjusted that they may offer the same resistance to compression at all points as would be offered by the arch, if compressed to a like degree. The idea is represented

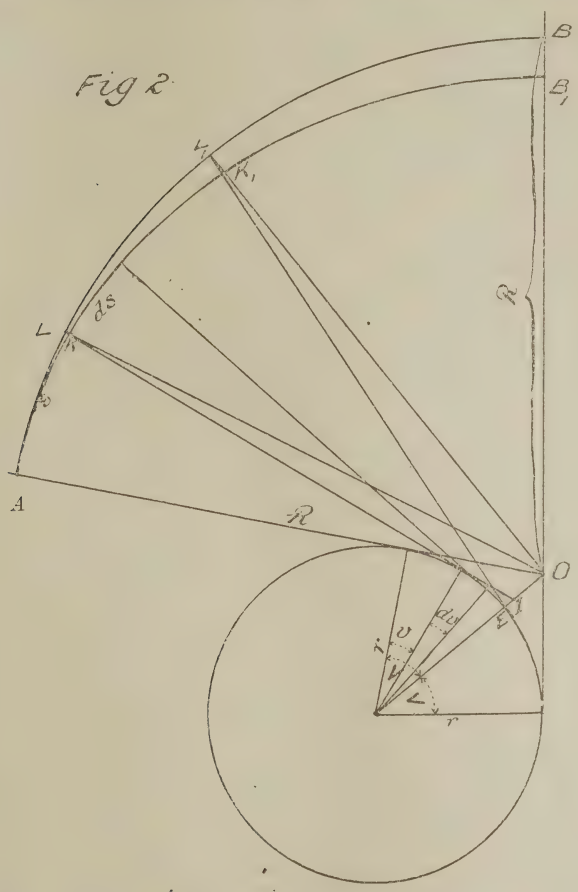
in the adjoining Fig. 1. AB is a leaf spring supported by springs of varying strength, s_1, s_2, s_3, &c., but all of originally equal length AC $= a$, and acted upon by forces k_1, k_2, k_3, &c , which deflect it into the new position AB_1. We desire to determine the form of AB_1 after compression ; also the distribution of the load between the leaf and spiral springs.



The problem appears a somewhat novel one, and at first sight the data for its determination seems insufficient. However, the real difficulty lies principally in not knowing in advance the exact form which the arch will assume under any load to which it may be subjected. It is clear that upon the form assumed by the curve for any given deflection, say one inch at the crown of the arch, will depend its modified length after compression, that is to say, the resistance in pounds for this deflection.

As regards the nature of the curve which the compressed arch would assume, certain inferences could be made with certainty that they must apply to the actual form. Owing to the symmetrical law of loading, it was safe to assume that the tangent at the crown after deflection, would still preserve its direction; also that *at* the abutment the tangent must remain unaltered ; for a *sudden* change in direction *at* the abutment must mean rupture of the arch from its end supports. Regarding the arch as a curved beam, certain known qualities of such beams made it clear that the form must be such, that its radius of curvature could only increase by successive increments *from* the abutments *towards* the crown ; that the moments of the external load and the abutment reactions by which the shape of the arch is defined must change continuously, and are not liable to reach a maximum or minimum value for some intermediate point between the abutments and the crown, and then change from increasing to waning values or the reverse.

Not to complicate the calculations too much in its earlier stages, it appeared de-irable to assume some curve which seemed suitable, and whose mathematical relations are determinable by calculation, and afterwards to test the correctness of the as-



sumption. The curve which was assumed for the deflected arch was that shown in Fig. 2, namely, the involute to (two) circular generating circles (evolutes). In this figure, AB represents one-half of the original undeflected arch, A being the abutment and B the middle point or crown. AB_1 is the corresponding

half arc after deflection, and BB_1 the movement at the crown For any given value of the half central angle 2V and radius R of the arch before deflection, we may determine the radius of the evolute for any assumed value of the crown deflection BB_1; also z, the shortening of the arc, or the difference between AB and AB_1; furthermore the radial distance LK, at any point L on the arc to the opposite point K on the involute, and the difference in direction of tangency of the two curves at these points. The main properties which concern us are the shortening z of the half arch AB for any value of R and 2V, the half central angle of the arch. It can be shown that

$$z = (\tfrac{1}{2}BB_1)2V,$$

or, for the shortening of the whole arch,

$$2z = BB_1 \times 2V.$$

That is, the compression of the whole arch equals the assumed deflection times the arc of the half central angle of the arch.*

For any point, L, whose angular distance from A is v, the offset, LK, is

$$LK = r\,(\tfrac{1}{2}\text{tang}V v^2 - \tfrac{1}{3}v^3).$$

For 20 points on the curve evenly distributed along the arc, the offsets expressed in percentages of BB_1 (the crown deflection), are as follows:

AL in $\frac{1}{20}$ of arc AB	1	2	3	4	5	6	7	8	9	10
LK in percentages of BB_1..	007	.028	.061	.104	.156	.216	.282	.352	.425	.500
AL in $\frac{1}{20}$ of arc AB	11	12	13	14	15	16	17	18	19	20
LK in percentages of BB_1..	.575	.648	.718	.784	.844	.896	.939	972	.993	1.000

* The term arc is used throughout the paper in its ordinary mathematical sense; namely, the ratio of the length of any arc of a circle to its radius, the angle being expressed in terms of π, not in degrees and subdivisions of degrees; the relation being $\pi = 3.14159 = 180°$. Hence, all angular values a, φ, ω, V, &c., always signify the length of the arc whose central angle is a, φ, ω, V, &c., but measured upon a circle whose radius is unity.

Having decided temporarily to consider the deflected arch as the involute determined by the deflection BB_1, we may proceed to determine the value of the spring reactions, or the uniformly distributed load which is required to produce a crown deflection BB_1, equal 1 inch in any section of arch 1 foot high. The external load of q lbs. per square foot will produce a pressure of qR lbs. in the section of the arch, and if t be the thickness of the arch at the point considered, then $\frac{q\mathrm{R}}{t} = s$ will be the strain per square foot, or hoop tension in the arch. The general law of compression is—

$$s : (144\,\mathrm{E}) = \lambda : \mathrm{L}.$$

If

(144E) = modulus of elasticity per square foot,

λ, the compression of the whole arch ($= 2z = \mathrm{BB_1 2V} = \frac{1}{12}\,a$; viz: for $a = \frac{1}{2}$ central angle and $\mathrm{BB_1} = 1$ inch $= \frac{1}{12}$ foot),

L = Length of the whole arc $= 2\mathrm{R}a$;

For which values our formula becomes,

$$\frac{q\mathrm{R}}{t} : (144\mathrm{E}) = \tfrac{1}{12}a : 2\mathrm{R}a, \text{ from which}$$

$$q = \frac{\frac{1}{12}(144\mathrm{E})t}{2\mathrm{R}^2},$$

q being the force per square foot to produce 1 inch deflection at crown, t and R^2 being expressed in feet.

Having now settled upon an expression for the spring reactions (under the assumption that the deflected arch will take the involute form), we may proceed to determine the proportion of the load which will be sustained by the beam, and what portion will be borne by the springs (*i. e.* by arch compression).

In our calculations for the Bear Valley Dam we doubled the value of the spring reactions, which was equivalent to assuming a modulus twice as great, or double stiffness for the material in a horizontal sense that it was assumed to possess in a vertical sense. The reason for doing this was that the dam is built of long stones with relatively less mortar joints, horizontally, and the modulus of the granite undoubtedly being greater than that

for mortar, we made this concession, being for our purposes quite willing to give the benefit of any doubt that might exist in favor of arch action. We used a modulus of 3,000,000 for the arch force and only 1,500,000 per square inch for the beam. In all subsequent calculations a modulus of 1,500,000 lbs. was used. The absolute value employed was probably rather small; however, except in the case here referred to, where a relatively greater value is used for one portion of the masonry than for another (the masonry being imagined to be stiffer in one direction than another), it is perfectly immaterial what value be taken for E, as long as relative, not absolute deflections are considered. The modulus is a common factor of all terms, hence is always eliminated.

The solution is not a difficult although not a direct one, but obtainable by the method of approximations.

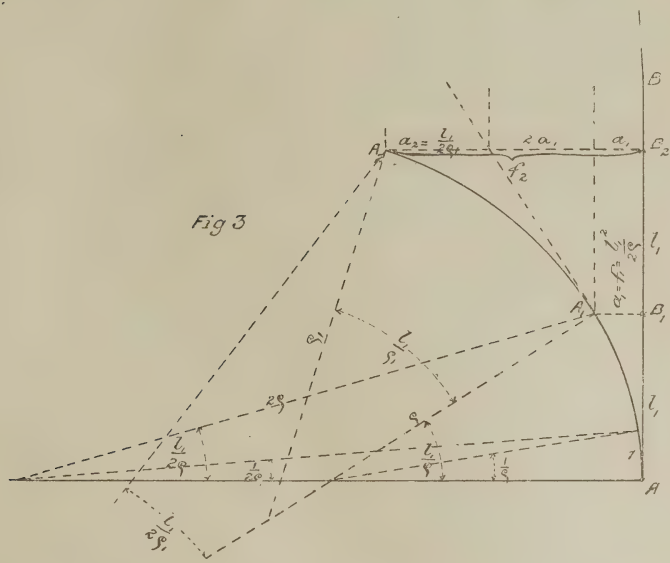
Were the beam unsupported entirely and subject to no spring reactions, the shape which the beam would assume under its load and its deflections at all points would be easily determined from the equation of the elastic line, which in its simplest form is

$$\frac{1}{\rho} = \frac{M}{ET}$$

ρ being the radius of curvature at any point for which the moment of external forces is M, and the moment of inertia of the cross-section of the beam at that point being T (namely for rectangular beams one foot wide and t feet high, $T = \frac{1}{12}t^3$), all measurements being in feet.

From inspection of Fig. 3 it will be seen, if we consider a small part of the elastic line as a circular arc of radius ρ, that the value $\frac{1}{\rho}$ is the central angle and $\frac{1}{2\rho}$ the deflection angle corresponding to a length of the arc 1 foot long. By considering the whole beam divided into n equal parts, each of the length $\frac{l}{n} = l_1$, then if n be taken sufficiently large we may consider for the small length l_1 the radius ρ still unchanged for the whole element l_1, and then suddenly compounded with a new radius ρ_1, which may again be considered as describing an arc which, for

an equal length $\frac{l}{n} = l_1$ may again be substituted without error for the corresponding length l_1 of the elastic line. Thus, by suitable selection of n, a compound curve may be substituted for



the elastic line, which it will correspond to, to within any desired degree of accuracy. Similarly $\frac{l_1}{\rho}$ and $\frac{l_1}{2\rho}$ will represent respectively the central angle and the deflection angle for a length of curve l_1. As we are dealing with very small angles, we are warranted in setting tangent $\frac{l_1}{2\rho}$ for $\frac{l_1}{2\rho}$ whence for the linear offset or deflection of the point A_1 from the tangent AB, we have—

$$f_1 = A_1B_1 = \frac{l_1^2}{2\rho}$$

or inserting for $\frac{1}{\rho}$, its value from the equation of the elastic line,

$$f_1 = a_1 = \frac{l_1^2 M}{2ET}.$$

For E we must here write 144E, if we wish E to represent the modulus per square inch; futhermore, if f_1 is to be represented in inches, then a factor 12 must be introduced and we have

$$f_1 \text{ (in inches)} = \frac{12Ml_1^2}{2(144E)\frac{t^3}{12}} = \frac{Ml_1^2}{2Et^3} = a_1 \text{ (in inches).}$$

Now if we represent by the letter a the deflection from the tangent to the curve at the last preceding point, and by f the total deflection from the original tangent AB, then at the second section from the base we will have

$f_2 = A_2 B_2 = f_1 + 2a_1 + a_2 = 3a_1 + a_2$, where a_2 would be

$a_2 = \frac{M_1 l_1^2}{2Et^3}$ and the deflection at any point will be as follows:

$$f_1 = a_1$$
$$f_2 = 3a_1 + a_2$$
$$f_3 = 5a_1 + 3a_2 + a_3$$
$$f_4 = 7a_1 + 5a_2 + 3a_3 + a_4$$

etc., etc.

$$f_n = (2n-1)a_1 + (2n-3)a_2 + (2n-5)a_3 + \ldots + \ldots + 5a_{n-2} + 3a_{n-1} + a_n$$

For the Bear Valley dam we have divided the height 43 feet into ten parts, whence $l_1 = 4.3$ feet, and using a modulus of $1\frac{1}{2}$ million, our deflection formula becomes—

$$f \text{ (in inches)} = \frac{M\,4.3^2}{3{,}000{,}000t^3}$$

from which and the preceding the elastic line for the unsupported beam was calculated (see sheet 2, right hand side). This strain sheet also shows the moments of the external forces acting upon the beam, namely the moment of water pressure acting horizontally, shown as a curve in broken lines; then the same modified for the influence of vertical water load on the back of the wall and the influence of excentricity of the weight of masonry, shown as a curve with a full unbroken line. The or-

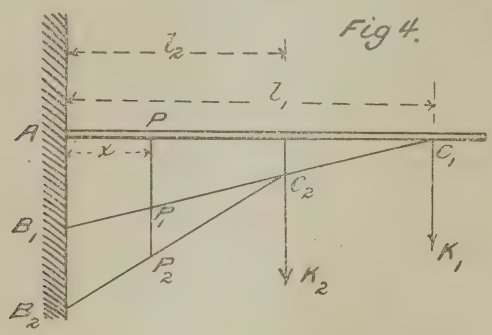
dinates to this curve, measured horizontally from the axis AA, are the moments used for calculating the deflections of the unsupported beam.

Now, as regards the action of the spring forces, if we draw them into the calculation (presupposing the formula to have been tabulated for all required dam thicknesses), it is clear that the unsupported beam has deflected more at all points than it would have deflected had elastic springs opposed its deflection. On the other hand, if we assume that the springs really acted during the first unsupported deflection and were actually compressed *to the full extent* of the deflections for the unsupported beam, it is evident that the resistance so computed would be *greater* than the beam would really be subjected to. For had spring resistances been introduced into the original calculation, the beam would have been deflected less than our calculation showed; hence, the springs themselves would have been less compressed than to the extent of the deflections of the unsupported beam. The curve marked "spring reactions, corresponding to deflections of unsupported beam," gives these limiting values for the spring reactions, measured horizontally from the axis A^1A^1.

Now, if we draw these reactions *with their excessive values* into the calculation, calculate the values of the resisting moments which they would exert at each section of the beam, deduct their values from the moments used to determine the elastic line for the unsupported beam and use the residual moments to calculate a new elastic line, we can predict that this line will be deflected *less* at all its points than would the beam if it rested on the actual springs; for these deflections were calculated with a greater spring resistance than would actually be exerted. The true elastic line must therefore lie somewhere *between* the first and last calculated line, which is shown on sheet 2 and marked "1st approximation to the elastic line of supported beam."

As regards the moments of the spring resistances which we assumed to have been calculated in the calculation which has been just outlined, their determination is very simple, and graphical methods are very appropriate. From the curve of spring reactions we know the *rate* of spring resistance at each

section of the beam. For this curve, the area embraced between any two sections and the curve and the axis represents the amount of spring resistance acting on this section of the beam, and the center of pressure of the reactions on this section must pass through the center of gravity of the enclosed figure. In our calculations we considered it sufficiently close to take a mean between the extreme values of the spring forces at the top and bottom of any subdivision, multiplying it into the height of the subdivision, 4.3 feet, and considering the product as a concentrated load acting at the center of the section.



Now, to recall an elementary graphical construction—see Fig. 4—the force K_1 will produce at the support, A, a moment K_1l_1. If K_1l_1 be plotted to scale as the line AB_1, and B_1C_1 be drawn, then will the line PP_1 represent the moment of the force K_1 at the point P. If a second force K_2 act, its moment at A will be K_2l_2, and if this be plotted as the line B_1B_2 on the same scale as was before used, and B_2C_2 be drawn, then will P_1P_2 represent the moment which K_2 produces at P, and $PP_2 = PP_1 + P_1P_2$ will give the moment due to both the forces K_1 and K_2 at this point; and so on for any number of forces.

Upon this principle, the "curve of moments of spring forces corresponding to the deflections of the unsupported beam" was constructed. At any section, the ordinate to this curve, measured horizontally from the axes A^1A^1, gives the moment of spring resistances for this point. Strictly speaking, the line A^1A^1 should coincide with the line AA. To avoid too

great confusion of lines, the line A^1A^1 was used as an axis, whereby a known error of 100,000 foot-pounds was committed. With this error allowed for, the horizontal ordinate between this curve and the "curve of moments of the external forces" gives the residual moment to be used in calculating the elastic line, which we designated as the "first approximation to the elastic line of the supported beam."

From the deflections last determined, a new set of spring forces is obtained, which is shown as the curve of "spring reactions corresponding to deflections of the approximate elastic line." These resistances are evidently too small, for the last deflections were too small. By using these forces just as the last set of spring forces were used, a new set of deflections would be obtained which would be too great, but not so much too great as were the deflections of the unsupported beam, and between which and the last calculated line must lie the correct position of the properly supported beam. By alternately using in succession too small and too great values for the spring forces, closer and closer approximation to a solution may evidently be approached.

A much more direct method however exists: namely, if the original spring reactions be designated as

$$s_1', s_2', s_3', \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad s_{10}'$$

and the second set as

$$s_1'', s_2'', s_3'', \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad s_{10}''$$

and to the lower set one-third of the differences between these and the upper set be added, a new set of values of the form—

$$\left\{\begin{matrix} s_1''+\frac{1}{3}(s_1'-s_1'') \\ = s_1''' \end{matrix}\right\}; \left\{\begin{matrix} s_2''+\frac{1}{3}(s_2'-s_2'') \\ = s_2''' \end{matrix}\right\}; \left\{\begin{matrix} s_3''+\frac{1}{3}(s_3'-s_3'') \\ = s_3''' \end{matrix}\right\}; \ldots;$$

$$\ldots; \left\{\begin{matrix} s_{10}''+\frac{1}{3}(s_{10}'-s_{10}'') \\ = s_{10}''' \end{matrix}\right\}$$

will be obtained.

Now, if instead of the values s'', as was last proposed, we use these modified values s''' and considering them as spring forces, calculate their opposing moments and after deducting these

from the external force moments, use the residuals to determine new deflections for the beam, these deflections will give spring resistances almost identically equal to the assumed set s''',* and a practical adjustment is obtained at the second trial. The forces s''' form the curve marked "curve of adjusted spring reaction," their moments giving the "curve of spring moments (adjusted)" and these latter deducted from the "external force moments" form the "curve of moments adjusted for spring resistances." With these, the "elastic line adjusted for spring resistances" was calculated, which gives the form which would really be assumed by our beam under the influence of the given loads and spring reactions. The "curve of adjusted spring reactions" gives at any point the load per square foot borne by the arch at that point. The "curve of moments adjusted for spring resistances" gives the moment acting upon the vertical beam at any point, and the ratio of the ordinates of this curve to the ordinates of the "curve of moments of the external forces" give the percentages by which the bending strains in the beam have been relieved by the spring support. These percentages will be found in column 13 of table 1, which table gives all the main elements of the calculation described.

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*To show how close this approximation is to an exact solution, we give our figures.

The spring resistances $\frac{(s_1''' + s_2''')}{2}$; $\frac{(s_2''' + s_3''')}{2}$; . . . . ; $\frac{(s_9''' + s_{10}''')}{2}$ assumed to be the spring resistances reduced to the center of each section, were:

225 236 216 191 160 122 85 50 21 5

The corresponding values resulting from the elastic line calculated with the above assumed resistances were:

210.5 222.5 214.5 197.0 163.5 125.0 86.2 50.6 21.5 4.6

These differences would have affected the moment at the base of the beam, where the *ruling strain* is produced, by 3,430 foot-pounds, or about $\frac{3,430}{689,500} = .005$, or say one-half of one per cent.

The beam moments need a slight increase and another closer approximation might easily have been made, but this seemed indeed a superfluous refinement.

BEAR VALLEY DAM, TABLE 1.

Showing the Main Elements of the Calculations Graphically Represented in Sheet 2.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Number of Section.	Depth from top of Dam or below Water Surface in feet.	Thickness of Wall = t in feet.	Weight of superincumbent Masonry—at 160 lbs. per cubic foot.	Weight of Water acting vertically on face of Dam. Lbs.	Moment (in foot lbs.) From Weight of Masonry	Moment (in foot lbs.) From Water load on face of Dam	Moment (in foot lbs.) From Horizontal Water Pressure	Moment (in foot lbs.) Total external Moment	Spring reactions corresponding to a deflection of 1 in. (double value; E = 3,000,000 lbs. pr sq. in.)	Deflections of unsupported Beam (inches). (E = 1,500,000 lbs.)	Moment of Forces adjusted for Spring resistances (foot lbs).	Ratio of adjusted Moments to external Force Moments.	Ratio of Moment, taken up by Springs, to external Force Moments.	Deflection of adjusted Elastic Line or Compression of Springs (in inches).	Adjusted Spring Loads. Lbs. per square foot.
					+	—	+	+							
0	0	3.72	0	0	0	0	0	0	489.6	.54255	0	.....	.....	.394219	193.0
1	4.3	4.20	2724	64	322	124	827	1025	665.6	.46659	—975	.....	.....	.342336	228.0
2	8.6	4.68	5777	257	1360	520	6615	7455	741.8	.39116	—940	.....	.....	.290316	217.0
3	12.9	5.16	9158	576	2670	1210	22326	23786	817 8	.31725	+4970	.206	.794	.238464	212.0
4	17.2	5.63	12869	1024	5680	2220	52920	56380	892.4	.24626	+23480	.417	.583	.187647	182 0
5	21.5	6.11	16908	1606	9170	3615	103359	108914	968.4	.18037	+58500	.537	.463	.139223	145.0
6	25.8	6.59	21276	2310	13900	5400	178604	187104	1044.4	.12136	+116700	.624	.376	.094894	105.0
7	30.1	7 07	25973	3150	19400	7590	283617	295427	1120.0	.07152	+203100	.689	.311	.056621	67.5
8	34.4	7.54	30998	4110	26280	10200	423358	439638	1195.0	.03316	+324000	.738	.262	.026549	33.7
9	38.7	8.02	36353	5200	34450	13350	602790	623890	1271.2	.00857	+484300	.776	.224	.006921	9.3
10	43.0	8.50	42037	6423	43950	17100	826870	853720	1347.2	0	+6 9500	.807	.193	0	0

The curve of moments of the external forces (or the values in column 9), together with data in columns 4 and 5 of table 1, afford convenient data for determining the maxima tensile and compressive strains in any section of the beam under the assumption that no arch action takes place, that is to say, for a purely gravity treatment. By using the "curve of moments adjusted for spring resistances," or column 12 in place of column 9 (or its equivalent curve), the strains in the beam relieved by spring resistance may be determined. These values together with the line of strain in the dam section under each of these conditions of loading, are shown upon the strain sheet (sheet 2).

Assuming the involute theory to be correct, and our very liberal assumption of double stiffness in the horizontal layers to be warranted, then it would appear that the effect of arch resistance is to reduce the bending moments at the bottom of the dam by about 19 %. At higher points in the section the relief is greater (passing up to a point of no bending strain at all a little below Section 2, beyond which point in the supported beam, the moments change their sign and become negative). The bottom moment, however, fixes the ruling strain, and the percentage of relief at the bottom is consequently the determining element in estimating the extent of arch relief. Whether it be within the capacity of the masonry to withstand strains such as our strain sheet shows without rupture, is purposely overlooked for the present.

It may be objected that our hypothesis that the arch would assume the involute form under compression was an arbitrary assumption ; also that besides arch reaction, independent resistances to deflection might present themselves through "beam action" on the part of the curved layers of the dam; furthermore, that in our calculations only the central section of the dam has been considered and no reference been made to the action of other vertical sections of the dam.

We propose now to test the "involute theory" by considering the curved layers as horizontal curved beams with immovable terminals ; to determine directly (independent of any prior assumption) the form which they would assume under loads acting normally to their surfaces, *i. e.* convergent to a common central

point, and to determine the strains which would be produced in them for given deflections, or for given loads.

The theory of the "Curved Elastic Beam" is treated of in the more advanced works on Mechanics, but the deductions are probably not so familiar to most practicing engineers as to warrant easy conversancy with them.

A treatment, moreover, for loads such as we have specified, namely *radial loads,* is not one which we remember to have ever seen, and from the purely special nature of its application to our present case believe that it may never have been made before. We therefore insert a brief reference to the theory of the elastic beam, condensed from Professor Ritter's text book, and extract the formulas which for our purposes are fundamental ones, before proceeding to the special development which we require.

Treatment of the Arch as a Curved Elastic Beam Loaded with Radially Acting Loads. General Characteristics and Fundamental Equations of the Elastic Line for Curved Beams.

In the theory of the elastic beam, it is shown that when the beam is originally curved, instead of straight, that similar general conditions exist as in the case of the straight beam ; that a neutral axis exists, which when the beam is deflected under a load suffers no strain, and whose length therefore is not changed; that all fibres, on either side of this neutral axis, have to adjust themselves to the load by being either lengthened or shortened, thereby assuming tensile or compressive strains, according to their position with reference to the neutral axis ; that these strains form a system of parallel forces, those on the one side of the neutral axis acting in the opposite direction from the forces acting in the fibres on the opposite side of the neutral axis; that the combined action of all the forces in any one radial plane is to form a couple of forces, the moment of which opposes, and is equal to the moment of the outside forces, at each section of the beam. It is also shown that for a beam of rectangular section, the position of the neutral axis is no longer in the center of the beam, but is located nearer to the center of curvature ; that its eccentricity depends upon the ratio of the depth of the beam

to its radius of curvature before the beam is bent; that the formula

$$\frac{s}{w} T = M$$

which applied to the straight beam, no longer rigidly applies to curved beams, but has to be modified to

$$M = \left(\frac{s}{w} T\right) N,$$

N being a constant determined by the value of $n = \frac{h}{R}$ (where h equal the height, and R the radius of the beam) such that for rectangular beams

$$N = \frac{\frac{1}{6}\left\{n - \log \text{nat. } (1 + n)\right\}}{\left(\frac{1}{2} + \frac{1}{n}\right) \log \text{nat. } (1 + n) - 1}.$$

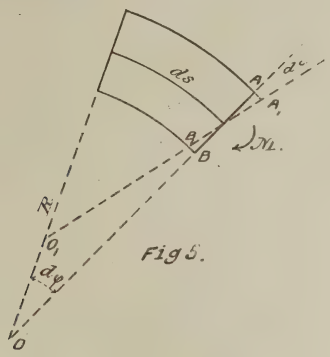
If w equal the height of the neutral fibre above the bottom of the beam, then it is shown that, when $n = 10$, $n = 2.888$, and $\frac{w}{h} = 0.317$; when $n = 1$, $N = 1.287$ and $\frac{w}{h} = 0.443$; when $n = 0.1$; $N = 1.033$ and $\frac{w}{h} = 0.492$; when $n = 0$, $N = 1$ and $\frac{w}{h} = 0.5$.

When the ratio n becomes nearly zero—that is to say, for beams of large radii compared with their depth—the value of N becomes so nearly unity, and the neutral axis in that case is so little removed from a central position in the beam that the formula $\frac{s}{w} T = M$ can be used without appreciable error. In this formula, s = maximum strain in the fibre farthest distant from the neutral axis, w = distance of this fibre from said axis, T and M being the moments of inertia and the moment of the external forces, acting at the section.

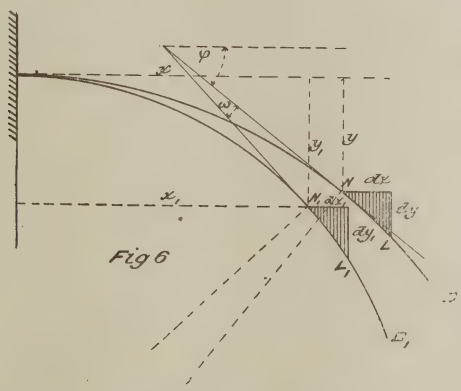
In the development of the differential equation of the elastic line for the curved beam, it is first shown that the relation exists

(Eq. A) $$ETd\omega = Mds$$

(See Fig. 5) where, $d\omega$ is the infinitely small change in direction



between the terminal planes of a differential length of the beam, ds (whose original curvature was $d\varphi$) under an external load which, at the section AB, produces a moment M, acting in the manner shown.



By a comparison of the two shaded triangles, in the adjoining Fig. 6—if the same be imagined to be so placed upon one another that the point N fall upon N_1, and horizontal sides still re-

tain their horizontal direction—two expressions may be obtained for the angle ω (expressed in terms of arc, of course), viz :

(Eq. B) $$\omega = \frac{dy_1 - dy}{dx}$$

(Eq. C) $$\omega = \frac{dx - dx_1}{dy}$$

By inserting into equation A (in any particular case) the special values for M and ds, which the curved shape of the beam and the law of its loading furnish, and then integrating between the limits 0 and ω on one side and 0 and s upon the other, the value of ω is obtained from the equation

$$\text{ÉT}\ \omega = \int_0^s \text{M}ds = \text{Ms},$$

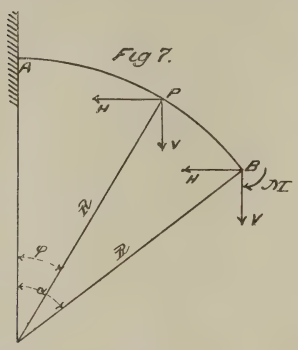
where ω represents the whole change in direction between the tangent to the curve at N and that at N_1 after the beam is bent. When this is done, the value thus obtained for ω may be successively inserted in equations B and C ; after which, by performing a second integration, the movement which the point N will undergo, will be given in a horizontal sense from the one calculation, in a vertical sense from the other. These three derived equations give the direction of the elastic line and the coordinates of any desired point ; hence fully determine its form.

Prof. Ritter, in his "Lehrbuch der Hoeheren Mechanik,"* applies the calculations which we have indicated, to beams of circular curvature, and develops the elastic line for the case of a vertical force working at the end of the beam, for a horizontal force applied to the end of the beam, and also treats the case where a couple of forces is applied at the end. He also considers the deflections which will be produced at any point of the beam beyond the point of application of the load, whether the load be vertical, horizontal, or a couple ; after which Ritter shows the change in length of the beam due to compressibility of the material.

The results of all these calculations are necessary to us in our

*Part II, "Lehrbuch de Ingenieur Mechanik," by August Ritter, published by Carl Rümpler, Hanover, 1876.

treatment of the arch as a curved beam, and the consideration of the elastic changes which are produced under the influence of continuous loads which all tend towards a common center, or act normally to the arch. We therefore transcribe a series of equations which we have numbered both with plain figures, and with figures with asterisks attached to them, and which it is believed a reference to the annexed figure (7) will make sufficiently clear as regards the cases to which they apply. The formulæ which are numbered with plain figures give the changes of co-ordinates produced at any point P, whose distance from A is the arc φ, whose new co-ordinates are x_1 and y_1, and whose original co-ordinates were x and y. The corresponding formulæ with asterisks, give the changes which take place at the end of the beam, B, whose settlement and horizontal shifting are then respectively called σ and ξ.



All these formulæ can be found with lucid deductions in Ritter; their development at this place is of course impossible, on account of limited space. They are to us fundamental equations, and we assume them as known.

Couple of forces, of moment M, *applied to the end of the beam.*

1 $\quad ET\omega = MR\varphi$

2 $\quad ET(y_1 - y) = MR^2(\varphi\sin\varphi + \cos\varphi - 1)$

3 $\quad ET(x - x_1) = MR^2(\sin\varphi - \varphi\cos\varphi).$

1* $\quad ET\omega = MR\alpha$

2* $\quad ET\sigma = MR^2(\alpha\sin\alpha + \cos\alpha - 1)$

3* $\quad ET\xi = MR^2(\sin\alpha - \alpha\cos\alpha).$

Vertical force at end of beam.

4 $\quad ET\omega = VR^2(\varphi\sin\alpha + \cos\varphi - 1)$

5 $$ET(y_1-y)=VR^3\left\{\sin\alpha(\varphi\sin\varphi+\cos\varphi-1)+\frac{\varphi}{2}+\frac{\sin 2\varphi}{4}-\sin\varphi\right\}$$

6 $$ET(x-x_1)=VR^3\left\{\sin\alpha(\sin\varphi-\varphi\cos\varphi)+\frac{\sin^2\varphi}{2}-(1-\cos\varphi)\right\}$$

4* $$ET\omega=VR^2(\alpha\sin\alpha+\cos\alpha-1)$$

5* $$ET\sigma=VR^3\left\{\alpha(\tfrac{1}{2}+\sin^2\alpha)+\tfrac{3}{4}\sin 2\alpha-2\sin\alpha\right\}$$

6* $$ET\xi=VR^3\left\{\frac{3\sin^2\alpha}{2}+\cos\alpha-1-\tfrac{1}{2}\alpha\sin 2\alpha\right\}$$

Horizontal force applied at end of beam.

7 $$ET\omega=HR^2(\sin\varphi-\varphi\cos\alpha)$$

8 $$ET(y_1-y)=HR^3\left\{\tfrac{1}{2}\sin^2\varphi+\cos\alpha(1-\cos\varphi-\varphi\sin\varphi)\right\}$$

9 $$ET(x-x_1)=HR^3\left\{\tfrac{1}{2}\varphi-\tfrac{1}{4}\sin 2\varphi+\cos\alpha(\varphi\cos\varphi-\sin\varphi)\right\}$$

7* $$ET\omega=HR^2(\sin\alpha-\alpha\cos\alpha)$$

8* $$ET\sigma=HR^3\left\{\frac{3\sin^2\alpha}{2}-\tfrac{1}{2}\alpha\sin 2\alpha+\cos\alpha-1\right\}$$

9* $$ET\xi=HR^3\left\{\tfrac{1}{2}\alpha(1+2\cos^2\alpha)-\tfrac{3}{4}\sin 2\alpha\right\}$$

Vertical Force at End of Beam; λ = Change of Length of Arc,

10* $$\lambda=\frac{VR(1-\cos\alpha)}{EF}$$

if F represent the area of cross-section of beam. The changes in horizontal and vertical direction caused by the shortening λ, are respectively:

11* $$\xi'=\lambda\cos\alpha=\frac{VR(1-\cos\alpha)\cos\alpha}{EF}$$

$$12^* \quad \sigma' = \lambda \sin\alpha = \frac{VR(1 - \cos\alpha)\sin\alpha}{EF}$$

Change of Length of Arc λ, *for a Horizontal Force* H, *at End of Beam.*

$$13^* \quad \lambda = \frac{HR\sin\alpha}{EF}$$

$$14^* \quad \sigma' = \frac{HR\sin^2\alpha}{EF}$$

$$15^* \quad \xi' = \frac{HR\sin\alpha\cos\alpha}{EF}$$

Vertical Force Q *at Point* P; *Change at End of Beam.*

$$16^* \quad \sigma = \frac{QR^3}{ET}\left\{\tfrac{1}{2}\varphi + \tfrac{1}{4}\sin 2\varphi - \sin\varphi + \sin\alpha(\varphi\sin\varphi + \cos\varphi - 1)\right\}$$

$$17^* \quad \xi = \frac{QR^3}{ET}\left\{\tfrac{1}{2}\sin^2\varphi + \cos\alpha(1 - \cos\varphi - \varphi\sin\varphi)\right\}$$

No further change takes place in direction of final tangent after passing the point P (see equation 4*, using φ in place of α); hence

$$ET\omega = VR^2(\varphi\sin\varphi + \cos\varphi - 1).$$

We require for our case also to know the changes produced by a radial load Q. These alterations may be obtained from Ritter's formulæ by successively substituting for Q its vertical and horizontal components, $Q\sin\alpha = H$ and $Q\cos\alpha = V$, or $Q\sin\varphi = H$ and $Q\cos\varphi = V$, as the case may require, and then after obtaining the changes produced by each component, combining the results in one formula. The formulæ which we have developed directly, have all been checked by this method, but were all obtained originally by direct development. Space will not permit of giving the complete development of the formulæ for radial forces (although they may be new). We will treat one case sufficiently fully, however, to illustrate the method of derivation and take one of the simpler cases:

A Radial Force Acting at the End of the Beam.

The force Q (Fig. 8) will produce at any point P a moment $M = Q$ times the arm $PP_1 = R\sin(\alpha - \varphi)$; hence, for this case,

$$M = QR\sin(\alpha - \varphi).$$

As we are dealing with a circle, the differential of the arc s is $ds = Rd\varphi$, from which for the infinitely small change $d\omega$ produced by the load Q at the end of the beam (see eq. A),

$$ET d\omega = M ds = QR^2 \sin(\alpha - \varphi) d\varphi.$$

Hence, to obtain the total change in direction of the line up to any point P, we have to sum all the differential changes $d\omega$,

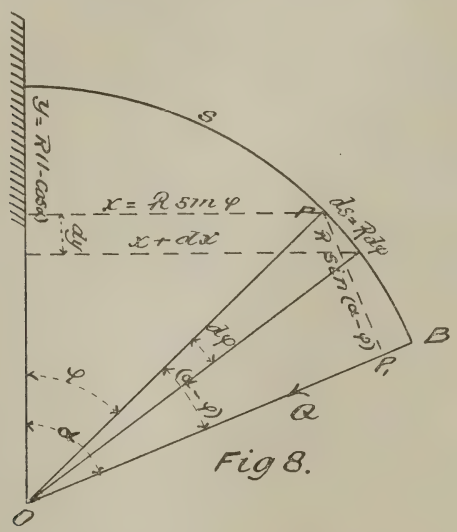


Fig 8.

for all the small arcs ds which collectively make up the arc $AP = s$; or, to obtain ω the total change, we integrate the above and have

$$ET\omega = \int_0^s M ds = \int_0^\varphi QR^2 \sin(\alpha - \varphi) d\varphi$$

which solved, after separating the integral into two integrals by expanding the term $\sin(\alpha - \varphi)$, gives

$$ET\omega = QR^2 \left\{ \sin\alpha \sin\varphi + \cos\alpha(\cos\varphi - 1) \right\} \text{ or}$$

18 $$ET\omega = QR^2 \left\{ \cos(\alpha - \varphi) - \cos\alpha \right\}.$$

If we wish to obtain the change of tangent direction at the end of the beam, we have only to integrate between the limits $\varphi = 0$ and $\varphi = \alpha$, from which we get

$$ET\omega = QR^2 \int_{\varphi=0}^{\varphi=\alpha} \sin(\alpha - \varphi) d\varphi = QR^2 \left\{ \cos(\alpha - \alpha) - \cos\alpha \right\}$$

18* $$ET\omega = QR^2(1 - \cos\alpha)$$

which could of course have been directly obtained from 18 by setting α in place of φ.

Having obtained the value of ω (eq. 18), we set it in eq. B, whence

$$\frac{dy_1 - dy}{dx} = \frac{QR^2}{ET} \left\{ \cos(\alpha - \varphi) - \cos\alpha \right\}.$$

But from the figure, $R \sin \varphi = x$, whence $dx = R\cos\varphi d\varphi$; substituting which

$$ET(dy_1 - dy) = QR^2 \left\{ \cos(\alpha - \varphi) - \cos\alpha \right\} R\cos\varphi d\varphi$$

$$= QR^3 \cos\varphi \left\{ \cos(\alpha - \varphi) - \cos\alpha \right\} d\varphi$$

which gives the relations of the infinitely small change in vertical position produced upon the small arc ds located at the point P; whence, by integrating between $\varphi = 0$ and $\varphi = \varphi$, we obtain the vertical settlement at the end of the whole arc s whose central angle is φ; that is

$$ET(y_1 - y) = QR^3 \int_0^{\varphi} \cos\varphi \left\{ \cos(\alpha - \varphi) - \cos\alpha \right\} d\varphi$$

which, after expanding $\cos(\alpha - \varphi)$ and multiplying by $\cos\varphi$ separates into

$$\mathrm{ET}(y_1 - y) =$$

$$= \mathrm{QR}^3 \left\{ \sin\alpha \int_0^\varphi \sin\varphi \cos\varphi d\varphi + \cos\alpha \int_0^\varphi \cos^2\varphi d\varphi - \cos\alpha \int_0^\varphi \cos\varphi d\varphi \right\}$$

from which, after performing the integrations indicated and suitably reducing, we get

$$19 \quad \mathrm{ET}(y_1 - y) = \mathrm{QR}^3 \left\{ \tfrac{1}{2}\sin\alpha \sin^2\varphi + \cos\alpha(\tfrac{1}{4}\sin 2\varphi - \sin\varphi + \tfrac{1}{2}\varphi) \right\}$$

If on the other hand we insert the value of ω from eq. 18 in eq. C, we get

$$\frac{dx - dx_1}{dy} = \frac{\mathrm{QR}^2}{\mathrm{ET}} \left\{ \cos(\alpha - \varphi) - \cos\alpha \right\}$$

and observing that $y = \mathrm{R}(1 - \cos\varphi)$, whence $dy = \mathrm{R}\sin\varphi d\varphi$,

$$\mathrm{ET}(dx - dx_1) = \mathrm{QR}^2 \left\{ \cos(\alpha - \varphi) - \cos\alpha \right\} \mathrm{R}\sin\varphi d\varphi$$

which equation gives the change in length (measured horizontally) in the small arc ds; whence by integration, we get for the change of position of a point P, whose distance from A is the arc $\varphi = s$

$$\mathrm{ET}(x - x_1) = \mathrm{QR}^3 \int_0^\varphi \sin\varphi \left\{ \cos(\alpha - \varphi) - \cos\alpha \right\} d\varphi$$

which integrated gives

$$20 \quad \mathrm{ET}(x - x_1) =$$

$$= \mathrm{QR}^3 \left\{ \sin\alpha(\tfrac{1}{2}\varphi - \tfrac{1}{4}\sin 2\varphi) + \cos\alpha(\tfrac{1}{2}\sin^2\varphi + \cos\varphi - 1) \right\}.$$

Now, if in equations 19 and 20 we set α in place of φ, we get, after suitably reducing terms,

$$19^* \quad \mathrm{ET}\sigma = \mathrm{QR}^3 \left\{ \tfrac{1}{2}\sin\alpha + \cos\alpha(\tfrac{1}{2}\alpha - \sin\alpha) \right\}$$

$$20^* \quad \mathrm{ET}\xi = \mathrm{QR}^3 \left\{ \tfrac{1}{2}\alpha\sin\alpha + \cos\alpha(\cos\alpha - 1) \right\}$$

Changes produced at the end of the beam by a radial force Q, *working at a point* P *between the support* A *and the end of the beam.*

$$21^* \qquad ET\sigma = QR^3 \left\{ \sin \alpha - \tfrac{1}{2}\sin \varphi + \cos \varphi \left(\tfrac{1}{2}\varphi - \sin \alpha\right) \right\}$$

$$22^* \qquad ET\xi = QR^3 \left\{ \tfrac{1}{2}\varphi \sin \varphi - \cos \alpha (1 - \cos \varphi) \right\}$$

ELASTIC ARCH WITH RIGID ABUTMENTS AND RADIAL LOADS.

Preliminary Treatment; Considering the Beam Elastic, But Not Regarding Compressibility of Material.

NOTE.—☞ *All the results obtained from this treatment need modification.*

The elastic conditions which exist in circular arches for vertical loads have been often discussed. As regards the case where the forces all converge towards the center of the arc, we know of no treatment and have therefore deduced formulæ to meet the deficiency.

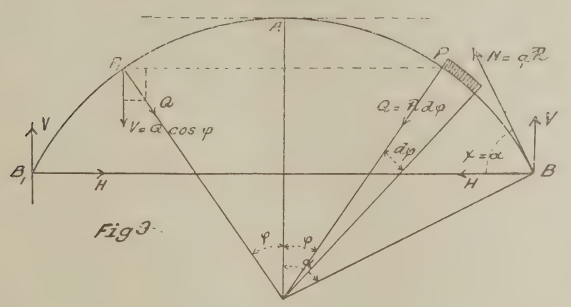


Fig 9.

If we regard a single load at the point P_1 (Fig. 9), we know certainly that the vertical forces at the abutments must be equal to the vertical component of the load, on account of the symmetrical nature of loading; seeing that for any point P_1 on one side of the arch, we may select a corresponding point P on the other side, which will be subjected to an equal load, and if we consider them conjointly, it is apparent that each abutment must carry an equal share of the double load, whence $V = Q \cos \varphi$, for any single pair of loads.

Whatever the form of the curve assumed by the arch after it is loaded, the tangent at the crown must remain unchanged in direction on account of the symmetry of the load. Besides the forces Q and V, there must also act at the abutment a horizontal force H, which for the present shall be left indeterminate and only be designated as the force H. Now in determining the settlement of the point A, it is immaterial whether we conceive the point A to move downward toward the abutments, or imagine the motion such that the abutments move upward toward the crown. The assumed rigidity of the abutments, however, permits no motion of the abutment B horizontally toward the crown A, the span of the arch being regarded as unalterable. Hence we can consider the half arch AB_1, for that matter as built into a solid wall, and consider the other half AB as a flexible beam acting under the influence of three forces Q, V and H, each of which will produce horizontal and vertical deflections at B, the amount of which may be obtained from our fundamental equations 1 to 22 inclusive.

As B is prevented by the conditions of the problem from moving horizontally, the combined influence of the three forces, as regards imparting horizontal motion to the point B must be zero, whence

$$\xi_Q + \xi_H - \xi_V = 0, \quad \text{or} \quad \xi_H = \xi_V - \xi_Q.$$

Using equation 6* and substituting $Q \cos \varphi$ for V, we have:

$$\xi_V = \frac{QR^3}{ET} \cos \varphi \left\{ \frac{3 \sin^2 \alpha}{2} + \cos \alpha - 1 - \tfrac{1}{2} \alpha \sin 2\alpha \right\},$$

furthermore, from eq. 22*,

$$\xi_Q = \frac{QR^3}{ET} \left\{ \cos \alpha (\cos \varphi - 1) + \tfrac{1}{2} \varphi \sin \varphi \right\}$$

and from eq. 9*

$$\xi_H = \frac{HR^3}{ET} \left\{ \tfrac{1}{2} \alpha (1 + 2 \cos^2 \alpha) - \tfrac{3}{4} \sin 2\alpha \right\}.$$

Hence,

$$\xi_H = \xi_V - \xi_Q =$$

$$= \frac{QR^3}{ET}\left\{ \cos\varphi\left\{\frac{3\sin^2\alpha}{2} + \cos\alpha - 1 - \frac{\alpha\sin 2\alpha}{2}\right\} - \cos\alpha(\cos\varphi - 1) - \frac{\varphi\sin\varphi}{2}\right\}$$

which easily reduced to

$$\xi_H = \frac{QR^3}{ET}\left\{ \cos\varphi\left(\frac{3\sin^2\alpha}{2} - \tfrac{1}{2}\alpha\sin 2\alpha - 1\right) + \cos\alpha - \tfrac{1}{2}\varphi\sin\varphi\right\}$$

Setting this value equal to the value obtained from eq. 9*, we obtain

$$H = \frac{Q\left\{ \cos\varphi\left(\frac{3\sin^2\alpha}{2} - \tfrac{1}{2}\alpha\sin 2\alpha - 1\right) + \cos\alpha - \tfrac{1}{2}\varphi\sin\varphi\right\}}{\tfrac{1}{2}\alpha(1 + 2\cos^2\alpha) - \tfrac{3}{4}\sin 2\alpha}$$

which last equation gives us the value of H in terms of Q.

Now if instead of Q we write $qRd\varphi$, considering it the uniform load q, acting upon an infinitely small arc $ds = Rd\varphi$, we can write instead of H, in the last formula dH, considering it the small horizontal reaction at the abutment, caused by the differential load $qRd\varphi$. Representing the bracket in the numerator by A and the denominator by B, we have

$$dH = \frac{qR}{B}d\varphi\left\{ A\cos\varphi + \cos\alpha - \tfrac{1}{2}\varphi\sin\varphi\right\}$$

and we obtain the horizontal reaction at the abutment, in case the whole arch is loaded with the uniform load q, by integration of the above equation, wherefore

$$H = \frac{qR}{B}\left\{ A\int_o^\alpha \cos\varphi\, d\varphi + \cos\alpha\int_o^\alpha d\varphi - \int_o^\alpha \tfrac{1}{2}\varphi\sin\varphi\, d\varphi\right\}$$

which integrated gives

$$H = \frac{qR}{B}\left\{ A\sin\alpha + \frac{3\,\alpha\cos\alpha}{2} - \tfrac{1}{2}\sin\alpha\right\}.$$

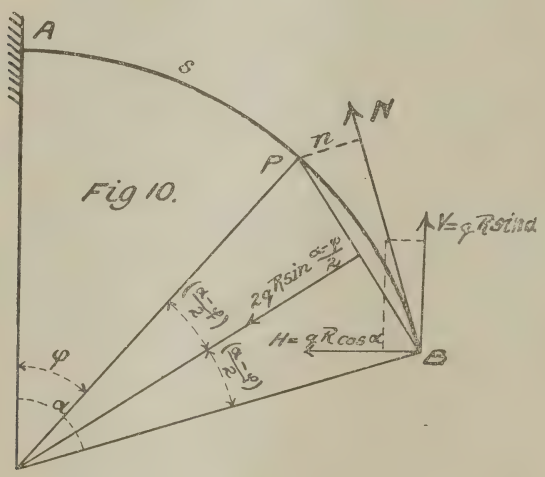
Now if we write for A and B the values which they represent, suitable reduction brings the bracket quantity in our last formula to $B \cos \alpha$, and we have

24 $$H = qR \cos \alpha$$

for the horizontal force at the abutments.

Upon the other hand we have seen that a single radial load Q produces at the abutments a vertical force $V = Q \cos \varphi$. Now, if we set $Q = qRd\varphi$, and set dV in place of V, we obtain by integration between the limits $\varphi = 0$ and $\varphi = \alpha$,

25 $$V = qR \sin \alpha$$



Referring to our figure (Fig. 9), the resultant N of the forces H and V forms an angle ψ with the horizontal, and this angle is given by the relation

$$\text{tang}\, \psi = \frac{V}{H}.$$

Now, setting for V and H the values just obtained, we have

26 $$\text{tang}\, \psi = \frac{V}{H} = \frac{qR \sin \alpha}{qR \cos \alpha} = \text{tang}\, \alpha.$$

Whence $\psi = \alpha$, or we see that the resultant is a tangent to the curve at the abutment. As to the value of N, it is easy to show that

$$27 \qquad N = qR.$$

Having determined the reactions which the abutments exert under the uniformly distributed radial load q, we will next proceed to determine what the settlement at the crown A, will be.

The vertical displacement σ, which a radial load Q acting at a point P would produce at the end of the beam B, provided no force acted at the abutment, can be directly taken from Eq. 21*, and substituting for Q, $qRd\varphi$, (that is to say, considering Q the uniformly distributed load upon an infinitesimally small arc $Rd\varphi$); corresponding to which modification, we set $d\sigma$ in place of σ. After making these changes, the integration of the modified equation will give σ, the total settlement at the end of the beam; viz.:

$$\sigma = \int_{\varphi=o}^{\varphi=\alpha} d\sigma = \frac{qRQ^3}{ET}\int_o^\alpha \left\{ \sin\alpha - \tfrac{1}{2}\sin\varphi + \cos\varphi\left(\frac{\varphi}{2} - \sin\alpha\right)\right\} d\varphi$$

The integration of this equeation gives the value of σ which will be produced by the uniform radially acting load, and which we will call σ_Q,

$$\sigma_Q = \frac{qR^4}{ET}\left\{ \frac{3\alpha\sin\alpha}{2} + \cos\alpha - 1 - \sin 2\alpha \right\}$$

As regards the settlements σ_V and σ_H which the forces at the abutments will produce, we can obtain them directly from the fundamental equations, by setting $qR\sin\alpha$ in place of V in Eq. 5*, and substituting in place of H its value $qR\cos\alpha$, in Eq. 8*.

As regards the total settlement σ, the radial load and the horizontal force H tend to deflect the beam in the opposite direction from that in which V would bend it; hence the total settlement is,

$$\sigma = \sigma_Q + \sigma_H - \sigma_V.$$

After inserting for σ_Q the value above given, and introducing the values σ_V and σ_H from Eqs. 5* and 8* (modified in the

manner suggested), an equation for σ is obtained, which properly manipulated reduces to

$$\sigma = \frac{qR^4}{ET}\left\{\alpha \sin \alpha - \alpha \sin \alpha\right\} = 0,$$

that is to say, for equally distributed radial loads there should be no settlement at the crown of the arch.

A load acting at a point P whose distance from the point of support is the arc $s = R\varphi$ (see Fig. 10), can produce no further change in the *form* of the beam, beyond the point P, where the force acts; hence at the end of the beam, the tangent will be changed only to the extent which the direction of the tangent at P is changed. For a radial load Q at P, the extent to which the tangent at the end of the beam will be altered, may be obtained from 18*, if remembering what has just been said, we regard P as if it were the end of a beam AP, and appropriately substitute φ for α; then the change of tangent at P will be

$$ET\omega = QR^2(1 - \cos \varphi).$$

Now, setting for Q, $qRd\varphi$ and integrating between $\varphi = 0$ and $\varphi = \alpha$, we have

$$\omega_Q = \frac{qR^3}{ET}\int_0^\alpha (1 - \cos \varphi)d\varphi = \frac{qR^3}{ET}(\alpha - \sin \alpha)$$

which will give the tangent direction at B, for a uniform load q *on the whole arc* AB. By inserting in Eq. 4* for V its value $qR \sin \alpha$, and setting $qR \cos \alpha$ in Eq. 7* in place of H, we get the alteration which would be produced at the end of the beam by the forces at the abutment. Calling these ω_V and ω_H, and combining them with ω_Q, we get the total shifting at the end of the beam produced by the conjoint action of the uniform load, together with that due to the reactions which the load occasions at the abutments: that is,

$$\omega = \omega_Q + \omega_H - \omega_V.$$

If the indicated calculation be made, the right hand side of the equation reduce to zero, and we have

$$\omega = \frac{qR^3}{ET} \left\{ 0 \right\} = 0.$$

Hence the combined action of the load and its reactions at the abutments, should cause no change in the direction of the tangent at the abutment; from which we infer that there should be no free moment or couple of forces acting at the abutment.

We will next inquire what the moment in the curved beam at a point P (see Fig. 10) would be. We will consider the arc between P and the abutment B uniformly loaded with the weight q, per unit length of arc. We need not consider the load on the portion of the arch between P and the point of support, because none of the loads which are on that portion of the beam, can produce moments in the beam beyond their point of application, seing that we regard the arch as a beam free to move at its end, and have already provided the abutment reactions which a fixed beam, loaded along its *whole* length, would create. The loads between P and B are all radial and equal, (we are considering the case of uniform loads only); whence their resultant, Q must pass through the center of the circle, and be normal to the chord PB at its middle point. The magnitude of Q it is easy to see must be

$$Q = 2qR \sin\left(\frac{\alpha - \varphi}{2}\right),$$

namely the projection of the whole load $qR(\alpha - \varphi)$ upon the chord PB. The moment of this resultant force Q at P is

$$QR \sin\left(\frac{\alpha - \varphi}{2}\right) = 2qR^2 \sin^2\left(\frac{\alpha - \varphi}{2}\right).$$

As regards the influence of the projection of the load $qR(\alpha - \varphi)$ upon the versed sine of the arc PB, the forces balance; hence can produce no moment at P.

Now taking the point P as a center of moments, it is apparent that should there exist any surplus or free moment at P, it must necessarily be the difference between those of the forces Q and N, (which latter is the resultant of the abutment forces V and H.) Now $N = qR$, (Eq. 27) and its arm is

$$n = \mathrm{R}\left\{1 - \cos(\alpha - \varphi)\right\}, \text{ whence}$$

$$\mathrm{M} = q\mathrm{R}^2\left\{2\sin^2\left(\frac{\alpha - \varphi}{2}\right)\right\} - q\mathrm{R}^2\left\{1 - \cos(\alpha - \varphi)\right\}$$

but as the bracket quantities are equal (by plane trigonometry),

$$\mathrm{M} = 0$$

and as P is *any* point on the arc, the deduction is a general one; hence, for a uniformly distributed load, there should be no free moment at any point in the beam. However, if in the fundamental equation of the elastic line, (Eq. A) we contemplate the case $\mathrm{M} = 0$ for all points, then $d\omega$ must be 0 for all points; whence the conclusion would be that no change in the co-ordinates of any point could take place—or in other words, the form of the arch would undergo no change under a uniformly distributed radial load.

Now, if at any point P (see Fig. 11) we imagine the portion of the arch between the abutment and the crown entirely removed, we have shown that at the point P no free moment should exist; that is to say, all the forces acting at P must act normally to the section. If for the portion of the arch shown in Fig. 11 we set up the equation of moments, choosing O as a center, we obtain the equation

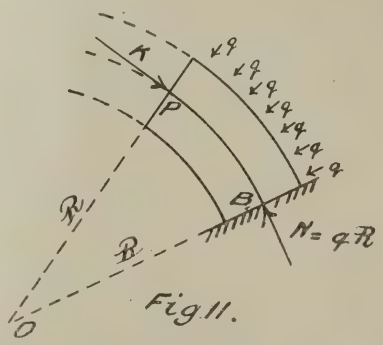


Fig. 11.

$$\mathrm{KR} = \mathrm{NR} = q\mathrm{R}.\mathrm{R}, \text{ or } \mathrm{K} = q\mathrm{R};$$

that is to say, the forces throughout the arch must act normally to the section and be constant at all points and equal to $q\mathrm{R}$.

We have thus far considered the arch under the assumption that it was flexible, but have not taken into account the changes

in the length of the arch, which the forces would produce by reason of the compressibility of the material. *All the deductions which have been made are, therefore, subject to modification.* However, before attempting to modify the preceding deductions by investigating what the influence of compressibility of the material will be, let us summarize the results which we have arrived at from the preliminary investigation. *Were the preceding conclusions correct,* we might formulate a law, about as follows:

"In a flexible arched beam, which is acted upon by a uniformly distributed load which at all points is normal to the beam, no change in form is produced; the forces which are induced by the load are constant at all points, and act at right angles to the section, being equal to the product of R, the radius of the circle, times q, the load per unit length of arc. Hence, under the assumption that no axial compression takes place along the arch (*as would be true for an arch constructed of a material whose modules of elasticity* E *were* ∞), the circular arc may be considered as a figure in perfect equilibrium under loads uniformally distributed over the arc and acting radially to the same."

For such an arch, no motion would be required for it to support loads of the character specified; from which we infer, that the stiffer the material against compressive strains, the more nearly the above law would hold good.

The reason for our not having considered the compressibility of the material up to the present point, is threefold.

First of all, the law which we have formulated corresponds entirely with the ordinary formula for "hoop compression" or arch pressure for radial loads—the formula, namely, which was used in determining the requisite section for the "Quaker Bridge Dam," comparing the curved and straight types.

Second—Had we regarded axial compression from the start, our investigations would have been much complicated.

Third—That we are now able to treat the effect of compressibility as a separate factor in the investigation, with a freedom which will hereafter become manifest.

Modifications Arising out of the Compressibility of the Arch Material.

For the case of a vertical or horizontal force acting at the end of a beam, the formulæ for the compression are developed in Ritter and will be found in our general equations 10 to 16. For a radially directed load, we will develop the formulæ. It might at first sight appear that the force Q, being normal to the arc at B (see Fig. 12), would exert no influence upon the length of the line. The force Q is normal to the curve at B, but in order to be borne by the beam, it must be transmitted to the point of support A, which can be done only by its successively passing through, and influencing each element of the arc between B and A. Hence, while the force Q *is* normal to the arc *at* B, it may be said to be normal to it at no other point. Now let us consider a differential of the arc *ds*, at P. The force Q at this point can be resolved into two parts, the one $Q \sin(\varphi - \psi)$, tangential to the curve; the other $Q \cos(\varphi - \psi)$, normal to the same.

The radial component can produce no change in the length of this particular element *ds*, and can be disregarded; the other component, $Q \sin(\varphi - \psi)$—the tangential one—will produce a shortening of the elementary arc *ds* which we will call $d\lambda$. The value of $d\lambda$ will be given by the ratio,

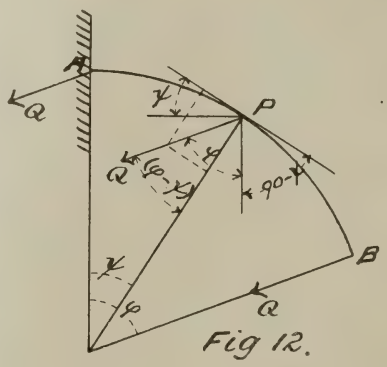


Fig 12.

$$\frac{d\lambda}{ds} = \frac{Q \sin(\varphi - \psi)}{F} \div E = \frac{Q \sin(\varphi - \psi)}{EF} = \frac{d\lambda}{R d\psi}$$

if F represent the cross-section of the beam; from which

$$d\lambda = \frac{QR \sin(\varphi - \psi)}{EF} d\psi$$

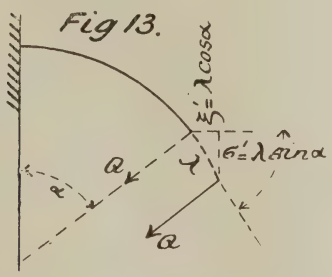
This equation gives the compression which the force Q will produce upon the element $ds = R d\psi$; whence, to obtain the shortening of the whole arc BA, we have to integrate the equation between $\psi = 0$ and $\psi = \varphi$, obsesving that in this integration φ is a constant quantity, not a variable one; hence,

$$28 \qquad \lambda = \int_0^{\varphi} d\lambda = \frac{QR}{EF}\int_0^{\varphi} \sin(\varphi - \psi) d\psi = \frac{QR}{EF}(1 - \cos\varphi),$$

and if we wish, for the sake of uniformity with our other formulæ, to specially designate the central angle for the whole beam by α, then we have only to write α instead of φ. Doing this, equation 28 becomes

$$28^* \qquad \lambda = \frac{QR}{ET}(1 - \cos\alpha)$$

Furthermore (see Fig. 13), the equations



$$29^* \qquad \sigma' = \lambda \sin\alpha = \frac{QR}{EF}\sin\alpha(1 - \cos\alpha),$$

and

$$30^* \qquad \xi' = \lambda \cos\alpha = \frac{QR}{EF}\cos\alpha(1 - \cos\alpha),$$

give the movements in vertical and horizontal direction, produced by the radial load Q at the end of the beam, and resulting from the compression of the material.

The preceding formula 28 gives the change in length for a *solitary load* Q at the end of the beam. If we wish to

determine the compression which the end of the beam will undergo, in case the whole beam is uniformly loaded with radial forces, we must substitute $qRd\varphi$ for Q in Eq. 28 and set $d\lambda$ in place of λ, and then integrate the equation between the limits $\varphi = 0$ and $\varphi = \alpha$; doing which we obtain

$$31 \qquad \lambda_Q = \frac{qR^2}{EF}\int_0^\alpha (1 - \cos\varphi)d\varphi = \frac{qR^2}{EF}(\alpha - \sin\alpha).$$

Besides the uniform load, however, we have the abutment forces V and H, both of which tend to shorten the arch by amounts which we will call λ_V and λ_H, and which can be obtained by setting in equation 10* and 13* the values $qR\sin\alpha$ and $qR\cos\alpha$ in place of V and H. These equations then become, after being slightly simplified in form,

$$\lambda_V = \frac{qR^2}{EF}\left\{\sin\alpha - \frac{\sin 2\alpha}{2}\right\}$$

$$\lambda_H = \frac{qR^2}{EF}\,\frac{\sin 2\alpha}{2}$$

Having now determined the influence which the forces produce separately, we may obtain the total compression arising from their joint action, by summing the separate effects; that is to say, by setting in the equation

$$\lambda = \lambda_Q + \lambda_V + \lambda_H,$$

the values which we have found. The result is an equation which easily reduces to,

$$32 \qquad \lambda = \frac{qR^2}{EF}\alpha = \frac{qR}{F}\cdot\frac{R\alpha}{E}$$

from which

$$\frac{\lambda}{R\alpha} = \frac{qR}{F} \div E$$

In this formula $R\alpha$ is the whole arc, and $\frac{qR}{F}$ the force acting in the arch per unit area; hence the compression is equal to that

which a straight beam of the same length as the arch would undergo, under the load $\frac{qR}{F}$ per unit of area. Furthermore, as the force throughout the arch is constant, it follows that the compression is equally distributed along the arch.

We have arrived mathematically at just what would have been predicted, *a priori;* nevertheless, the conclusion must be qualified with the reservation, that this value for λ is only correct, so long as the horizontal force H remains unchanged and continues to be $qR \cos a$, *which condition is generally not fulfilled.*

In any arch with immovable abutments, the span is fixed, and the vertical reaction V must remain unchanged, no matter what change in form the arch undergoes. It is different with the horizontal force H; this may and will alter in magnitude, with the changes which the arch undergoes under compression. Now if the actual horizontal force, instead of $H = qR\cos a$, assume some other value h, we can still write $h = H - (H - h)$ and represent the difference $(H - h)$ by another letter H_1, that is to say, instead of considering H reduced or increased to h, as the case may be, we may consider H still acting in undiminished force and another modifying force, H_1 associated with it, but nevertheless an independent factor in the case. The reason of this introduction of an auxiliary force will become apparent. Still continuing to regard the crown A as being fixed and B the movable, instead of the fixed point, we may imagine the forces which act on the arch as grouping themselves in the manner, and coming into action in the order following: we may consider the radial load and the forces V and H as acting in unison and forming a separate set, under whose conjoint action the compression λ really takes place according to Eq. 32, the abutment B thereby assuming the position B_1 (see Fig. 14). During this movement, B will have traveled in a horizontal sense through the small distance

$$\xi' = \lambda \cos a = \frac{qR^2 a \cos a}{EF},$$

the value of λ being that given in Equation 32 (compare Fig. 13). This will be the sole effect produced by this set of forces, and

having allowed for which, they need not be further regarded, except to remember that they produce a uniform compression qR at all sections of the arch.

We may next consider the force H_1 coming into action upon the beam, in such a manner that it tends to neutralize the movement ξ' and re-establish the span of the arch to its original value, hereby moving the end of the beam outward a distance

$$\xi'' = \frac{H_1 R^3}{ET}\left\{\tfrac{1}{2}\alpha(1 + 2\cos^2\alpha) - \tfrac{3}{4}\sin 2\alpha\right\}$$

which value we obtain from Eq. 9*. At the same time be it remembered, the the force H_1 will produce a lengthening influence upon the arc, which must not be lost sight of, and which, expressed in terms of H_1 (whatever the value of H_1 be), will be a quantity

$$\xi''' = \frac{H_1 R \sin\alpha\cos\alpha}{EF}$$

which we get directly from Eq. 15*.

Now, if we considered the force H_1 alone to completely overcome the movement ξ' and re-establish the span to its original width, one of the conditions of our problem would be fulfilled, but not another, namely that the direction of the tangent to the curve at the abutment shall remain unchanged; for no matter what form the arch may assume in taking up its load, the tangent *at* the abutment must retain its direction, as long as the arch remains *attached* to the abutment and does not crack away from the same, which latter is inadmissible,—for we are only trying to build up a formula which shall apply within the elastic limits, let alone those of ultimate strength. Now, the first change produced upon the tangent to the curve was when the arch was assumed to be shortened up from B to B′. During this motion the tangent shifted to the extent of the small angle $\Delta\omega$ (see Fig. 14), such that

$$R\Delta\omega = \lambda \quad \text{or} \quad \Delta\omega = \frac{\lambda}{R}$$

The effect which the modifying horizontal force H_1 would

exert on the tangent to the curve, may be obtained from Eq. 7*, viz.,

$$\omega_{H_1} = \frac{H_1 R^2}{ET} (\sin \alpha - \alpha \cos \alpha)$$

and this also would tend to increase the change of direction, not to overcome it. Now, the only way that the tangent can be re-established to its old direction, is with the help of a moment M, acting as shown in Fig. 14.†

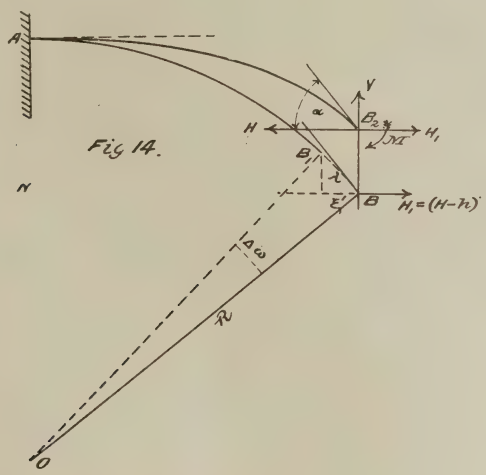


Fig 14.

However, this moment M will also exert an influence ξ'''' upon the width of the span, besides altering the direction of tangency by an amount ω_M,—an expression for which two values may be obtained from Eqs. 3* and 1*, viz:

$$\omega_M = \frac{MR\alpha}{ET}$$

$$\xi'''' = \frac{MR^2}{ET} (\sin \alpha - \alpha \cos \alpha)$$

†The moment M is simply the couple of forces produced in the fibres of the beam at their immediate surface of contact with the abutment; the internal resistances (on one side of the axis of the arch compressive, on the other side tensile) by which the arch material resists being wrenched from its contact with the abutment.

Under the influence of H_1 and M, B_1 will pass to a new position B_2, which must be in the same vertical as the point B, before any motion took place. This condition of an unchangeable width of span can only be fulfilled if

$$\xi' + \xi'''' = \xi'' + \xi'''$$

or, inserting the values of these quantities, if

$$(a) \qquad \frac{qR^2\alpha}{EF}\cos\alpha + \frac{MR^2}{ET}(\sin\alpha - \alpha\cos\alpha) =$$

$$= \frac{H_1R^3}{ET}\left\{\tfrac{1}{2}\alpha(1 + 2\cos^2\alpha) - \tfrac{3}{4}\sin 2\alpha\right\} + \frac{H_1R\sin 2\alpha}{2EF}$$

But the equation

$$\omega_M = \omega_{H_1} + \Delta\omega$$

must be fulfilled, since the tangent at the abutment must not be altered in direction, or

$$(b) \qquad \frac{MR\alpha}{ET} = \frac{H_1R^2}{ET}(\sin\alpha - \alpha\cos\alpha) + \frac{\lambda}{R}.$$

Eqations (a) and (b) contain only two unknown quantities, M and H_1; hence we can determine both the corrective force H_1 and the moment M at the abutment.

From (b) we obtain,

$$M = \frac{H_1R}{\alpha}(\sin\alpha - \alpha\cos\alpha) + \frac{\lambda ET}{R^2\alpha}$$

but from equation 32 we have,

$$\frac{\lambda}{\alpha}\frac{E}{R^2} = \frac{q}{F},$$

whence more simply

$$33 \qquad M = \frac{H_1R}{\alpha}(\sin\alpha - \alpha\cos\alpha) + q\frac{T}{F}.$$

If this value of M be inserted in Equation (a), an equation for H_1 is obtained which can be reduced to the form

$$34 \quad H_1 = \frac{qR}{\frac{R^2F}{T}\left\{\frac{(\alpha + \sin\alpha\sqrt{2})(\alpha - \sin\alpha\sqrt{2})}{2\alpha\sin\alpha} + \frac{\cos\alpha}{2}\right\} + \cos\alpha} \ddagger$$

Equations 33 and 34 may be said to solve the problem of the elastic arch for uniformly distributed loads; H_1 and M alone produce deflections in the arch and determine the shape of the elastic line, subject however to modification for the effect of the uniformly distributed shortening of the arc, which is produced under the combined action of the load and the abutment reactions $V = qR\sin\alpha$ and $H = qR\cos\alpha$.

---

‡Formula 34, for $\alpha = 0$ and $R = \infty$, becomes $H_1 = qR$; namely the first term in the denominator, though apparently of the indeterminate form $\infty^2 0$ is really 0, and $\cos\alpha$ becoming 1 for $\alpha = 0$, the whole denominator becomes 1. For the same value of α, the horizontal arch resistance $H = qR\cos\alpha$, also becomes qR; that is identically equeal to H_1, the modifying force. Hence the real value of the horizontal force at the abutment, or

$$H - H_1 = qR - qR = 0.$$

Formula 33 for this case gives $M = 0$; the first term being zero, as the bracket quantity at the limit becomes strictly $(1 - 1)$ and the second term zero, since in this term $\frac{q}{F}$ still stands for

$$\frac{\lambda E}{\alpha R^2} = \frac{\lambda E}{\frac{1}{2}\text{ length} \times R}$$

which is zero, both because $R = \infty$ and $\lambda = 0$, (the compressive force being zero). Of the forces at the abutment, only $V = qR\sin\alpha$ remains, and as $R\sin\alpha$ (for $\alpha = 0$, and $R = \infty$) is $\frac{1}{2}l = \frac{1}{2}$ the whole span, $V = \frac{1}{2}ql$, which is the correct value for any straight beam. Arch action ceases entirely, and our formula leads up naturally to, and makes way for the ordinary ones applying to straight beams, for which the deflections corresponding to any given load, or the load required to produce any given deflection may be found.

Had we attempted to apply the ordinary "hoop pressure" formula directly, without reference to equations 33 and 34, the resulting arch thrust at the abutment would have been $H = qR\cos\alpha = qR\cos 0 = qR = q\infty = \infty$, *a very different value from* $H = 0$. From this we see that the ordinary arch pressure formula may lead to misleading results, *when applied without correction for the elastic nature of the material.*

This remark is perhaps not without its significance as applied to the conclusions to which the formula led, relative to a dam of curved form, for the "Quaker Bridge Dam."

The influence which the modifying elements H_1 and M produce upon the internal strains in the arch, is easily determined by considering the moments which they will cause at any section. H_1 will cause a moment which will be proportionate to its arm; in other words, to the offset of the middle point of any section from the chord BN (Figs. 14 and 15).

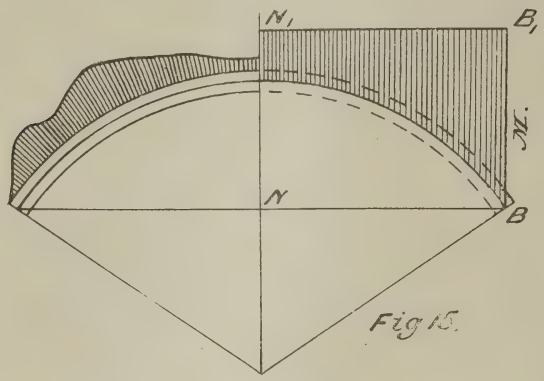


Fig 15.

The moment M will be unchanged for all sections of the arch, and as these two moments are opposed to one another, it is easy to see that their combined influence will be represented graphically by the ordinate to the central line of the arch, measured from the line B_1N_1, if BB_1 be made equal to M and $\frac{H_1}{M}$ be the unit used in plotting.

The greatest absolute value will be at the abutment B, where H_1 will produce no moment. The strains throughout the arch will no longer be equal at all points of any section, but will be generally greater along the inner line, and less at the outer line of the arch than the value $\frac{qR}{t}$. The resultant will at no section be strictly normal to the vousoir line, nor will the line of strain conform to the central line of the arch, as would be the case were the above value correct. The amount by which the strains will be modified, of course depends upon the load and the dimensions of the arch. By inserting H_1 and M, in equations 1, 2, 3, 7, 8, 9 and 1*, 2*, 3*, 7*, 8* and 9* and regarding also the values to be obtained from equations 32, 13*, 14* and 15*, the

change of form which the arch will undergo at any point may be determined;—or equations 33 and 34 may be used in combination with these, to determine for any arch the load q, which would be required to produce a given crown deflection (say one inch). This calculation has been fully carried out for the top section of the Bear Valley Dam, (for $R = 337$ ft.; $\alpha = 21° 15'$; $t = 3.72$ ft. and $E = 1\frac{1}{2}$ million pounds per square inch). The values for $(y_1 - y)$, $(x - x_1)$, σ, ξ and ω are as follows, for ten values of β corresponding to ten equally distant points on the arch betwen the crown and the abutment, (the units being inches and seconds of arc and the calculation made for a crown deflection of one inch).

β	0° 00′	2° 07′30″	4°15′	6° 22′30″	8°30′	10° 37′30″	12° 45′	14° 52′30″	17°00′	19° 07′30″	21° 15′
$y_1 - y$	1.0000	.9980	.9212	.8276	.7048	.5618	.4103	.2669	.1336	.0400	$\sigma = 0$
$x - x_1$	0	.0191	.0355	.0465	.0522	.0462	.0349	.0154	.0026	0	$\xi = 0$
ω	0	54″	104″	148″	183″	204″	208″	193″	156″	92″	0

NOTE.—In this table the values in lines 2 and 3 are modified so as to represent the real conditions; that is, a fixed abutment and a movable crown.

These results are graphically exhibited on sheet 3. The method of representation is the following. The circular arc which corresponds to the central line of the arch before deflection, is supposed to be unrolled upon the tangent to the curve at the crown, shown upon the diagram as the line AB_1, thereby the relative position of all points referred to the tangent to the curve at any point, is preserved unaltered. If then only special points of the resulting figure are of interest, it is evidently admissible to shorten up distances between these points to any desired extent.* Thus on the sheet (3), the lines $1\,1_1$, $2\,2_1$, $3\,3_1$, etc., represent the correct values of $(y_1 - y)$, and $1_1 1_{11}$, $2_1 2_{11}$, $3_1 3_{11}$,

*Thus in the diagram, AB_1 represents the whole length of the center line of the half arch (say 125 feet), but with its ten equidistant points contracted so as to be three-quarters of an inch apart. The local settlements and horizontal movements however are plotted to a scale of 7½ inches to 1 inch of actual change of position. The result is a much distorted, but correct exhibit of the *local* changes of position at the ten selected points.

etc., represent the proper horizontal changes $(x - x_1)$; the points 1_{11}, 2_{11}, 3_{11}, all being shown in their correct relative positions to the points 1, 2, 3, etc., which they occupied before the arch was subjected to a load. If a curve be passed through the points 1_1, 2_1, 3_1, etc., and also a curve be drawn through 1_{11}, 2_{11}, 3_{11}, etc., then these curves may be used to determine the values of $(y_1 - y)$ and $(x - x_1)$ for any intermediate point between any of the points plotted from calculation. Thus, if we desire to determine the changes for a point half-way between 3 and 4, we locate the point $3\frac{1}{2}$ on the line AB_1, midway between 3 and 4; then draw a line $3\frac{1}{2}\,3\frac{1}{2}_1$, such that the angle $B_1\,3\frac{1}{2}\,3\frac{1}{2}_1$ shall be

$$\beta_{3\frac{1}{2}} = \frac{\beta_3 - \beta_4}{2}.$$

A right angle to this line from the point $3\frac{1}{2}_1$, cuts the second curve at $3\frac{1}{2}_{11}$; then are $3\frac{1}{2}\,3\frac{1}{2}_1$, and $3\frac{1}{2}_1\,3\frac{1}{2}_{11}$ the required vertical and horizontal displacements of the point which before the deflection was located at $3\frac{1}{2}$, and after deflection assumed the position $3\frac{1}{2}_{11}$.

As the values of ω are very small angles, the direction of the deflected curve at any point, appears in this diagram as being parallel to the line AB_1, ω being too small to influence the curve at all perceptibility for the elementary arcs shown by the lines marked "direction of curve." We therefore show the values of ω by another method, namely in the form of a curve, the ordinates of which, measured from an assumed line A′B′, give the values of ω in seconds of arc. As all the elements of change are small quantities, we have magnified the crown deflection seven and one-half times (so that the line A0 is shown on the sheet as $7\frac{1}{2}$ inches instead of 1 inch), whereby all the linear movements are correspondingly enlarged. For comparison with the involute curve, which in our earlier calculations was arbitrarily assumed as being the curve which the deflected beam would assume, we have plotted the radial offsets of this curve which are given on page 82, employing a corresponingly enlarged scale. As these offsets (LK values) are radial to the original curve, they appear in our diagram as normal to the line AB_1 (the line of tangents). If we refer to our Fig. 2 (page 81), we see that as the line LI is normal to the involute curve, and OL normal to the circle, the angle OLI gives the angle between the tangents to

the two curves, or the change in direction between them at the point L, which change is entirely analogous to the value ω used in connection with the curved beam. The value of OLI is given by the formula

$$\text{tang OLI} = \text{CH}\,\frac{[\text{tang V tang}\,(\tfrac{1}{2}\text{V}) - \text{tang}\,v\,\text{tang}\,(\tfrac{1}{2}v)]\cos v}{\text{AO}},$$

in which formula

$$\text{CH} = r = \frac{\text{BB}_1}{2\,\text{tang V} - 2\text{V}}$$

from which, for the points treated in our calculation, the values of OLI expressed in seconds of arc (the term $\cos v$, however, being neglected) are as shown in the full line curve, on sheet 3. A comparison of the ordinates of this curve with the corresponding curve for the beam calculation—shown on the diagram as a broken line, and plotted with the values of ω from the preceding table—shows the difference in angular values between the beam curve and that of the involute at any and all points.

What has been said concerning the direction of small arcs of the beam curve, also applies to small arcs of the involute. The points K_1, K_2, K_3, etc., of the involute are shown on sheet 3 in their correct position relatively to points 1_{11}, 2_{11}, 3_{11}, but they do not correspond to these, the one set being radial offsets, and the other set, deflections parallel and normal to the tangent to the arch at the crown. The true distance between the curves is that shown on the diagram, between the horizontal lines drawn through the correspondingly indexed points 1_{11} and K_1, 2_{11} and K_2, etc.—of course bearing the enlargement of the scale in mind.

In order to show more apparently how nearly the deflected beam corresponding to the top layer of the Bear Valley Dam agrees with the involute, we have repeated the curves 1_{11}, 2_{11}, ... 10_{11} and K_1, K_2 . . . . . K_{10} on the same sheet,—showing them as the two curves A'' B_1—but in this case plotted to natural scale, the line AA'' being one inch by measurement. An inspection of the diagrams establishes the fact, that though the assumption that the arched layers of the dam become involute curves after deflection is not a correct one, still the involute in its general form and characteristics very closely

corresponds to the shape of the beam—at any rate the correspondence is a very close one, so far as the top layer of the dam is concerned.

For the different sections of the dam below the top layer, the calculation of the uniform load q, required in each case to produce a crown deflection of one inch, was made. This calculation was considerably simplified, by assuming that from the top down as far as the 5th section (inclusive), the span remained the same; that for sections 6 and 7, the length of the arch was seven-tenths, and for sections 8, 9 and 10 only one-half as long as on the top of the dam. By testing this assumption with the actual plans of the dam, it will be found to agree pretty closely with the facts, and that generally where an error was made, it assumes *shorter* lengths than actually exist at the corresponding heights of the dam. After obtaining these values of q, a comparison was made with the involute spring forces—the latter being reduced, however, to one half the values given in Table 1, column 10, assuming a modulus of 1,500,000 lbs., to correspond with the modulus used for the beam. The following table gives the results.

Section.	Assumed value of α (the half central angle).	q = the uniform load in lbs. per sq. ft. required to deflect the beam 1 inch at crown.	Value of q to produce same crown deflection, using involute formula (with E = 1,500,000 lbs. per sq. inch).	Ratio, beam load q divided by involute load q.
0	21° 15′ 00″	320.59	294.8	1.09
1	21° 15′ 00″	363.95	332.8	1.09
2	21° 15′ 00″	406.49	370.9	1.09
3	21° 15′ 00″	452.43	408.9	1.10
4	21° 15′ 00″	496.87	446.2	1.11
5	21° 15′ 00″	543.41	484.2	1.12
6	14° 52′ 30″	701.97	522.2	1.34
7	14° 52′ 30″	779.52	560.3	1.39
8	10° 37′ 30″	1607.98	597.5	2.70
9	10° 37′ 30″	1845.88	635.6	2.90
10	10° 37′ 30″	2037.09	673.6	3.03

An inspection of this table shows at once an interesting fact; namely, that while in every case the beam requires greater loads to deflect it one inch, than would be required were the involute theory a correct one,—still for each value of the half central angle α, the *ratio* remains practically constant, changing but slightly for such slow change in thickness of wall as occurs in the Bear Valley Dam.

The involute theory assumed the resistance to be dependent upon the radius, but independent of the angle included by the span. Our formula leads to the much more rational conclusion, that between beams of the same radius and thickness but of different lengths, shorter beams are much stiffer under the same load than longer beams are. The failure to express this fact is one of the weaknesses of the involute formula; a second, though less important one is, that it recognizes the influence of the thickness only in the first power, instead of as $\frac{t^3}{12t}$ or $\frac{t^2}{12}$, thereby omitting a factor $\frac{1}{12}t$, the influence of which mainly causes the slight change in the ratios already noticed.

The deficiency in the involute formula is a very obvious one, which, however, naturally follows any attempt to explain arch resistance to deflection as the result of internal arch compression *solely*. Without intending to draw distinctions closely between arch resistance ("hoop compression") and beam resistance, or to separate the total resistance of the beam into its elements, it may be observed from an inspection of sheet 3, that of the two cuves, the beam curve is a shorter curve than the involute, as all of its points lie nearer to the center; whence the real shortening of the arch under the action of its load, must be rather more than that resulting from the involute assumption, the involute formula apparently not allowing fully for the compression or "arch resistance;" hence beam resistance separately considered should be something less than the difference between 1 and the ratio shown in our table. Nevertheless, it is apparent that for beams of small central angle,—as in the case of the lower sections of the dam,—the re-

sistance is preponderately of a beam and not of an arch nature. In as much as this is true, the conclusion which we have generally assented to, regarding the secondary nature, and subordinacy of arch resistance to the deflections produced in the vertical fibres of the dam, needs some modification. As far as beam strains (as contra-distinguished from arch resistances) enter into the calculation, these are not dependent on the vertical flexures, but like them act "*ab initio.*"

From this it seems probable that for dams of relatively small span as compared to their curvature (especially if of considerable height also) the arch layers may really transfer a considerable portion of their load to the abutments. This has been frequently asserted; however, more as an expression of "engineering instinct," we believe, than as a fact supported by calculation. This is only one of the numerous anomalous conclusions to which the investigation of this subject constantly leads, and which probably have done much to foster lack of unanimity of opinion. It appears characteristic of the subject that what is true in one case does not hold true in all cases. General conclusions are difficult to arrive at, the subject being one which warrants special study for each set of conditions.

The new values of q correspond entirely to the former "spring forces" which were used to determine the distribution of load between the vertical beam and the horizontal arch. The former calculation might be repeated, and the new values used in place of the former ones, but it is deemed needless to do so. The deflections which would be obtained for the vertical member, would be but slightly less than those which the involute values would give (supposing the same modulus be used for the horizontal layers that is used for the vertical beam), the deflections being changed only to the extent to which the ratios in the last column of our table would alter the resisting moments. These moments, for the upper half of the dam, would be increased, about ten per cent; near the bottom they would be increased (say) three times. However, the lower springs affect the total moments but very slightly, and whether they be thrice increased or not, can affect the result but little, any effect produced by them having been much more than allowed for by the use of

springs of double value in our previous calculation; the assumption of a double stiffness in the horizontal layers, being one which will hardly be seriously regarded as waranted by the facts, and which was made solely for the purpose of showing more clearly, how little additional support appears to be furnished by the arched form of the dam, provided the calculation be based upon the assumptions heretofore made.

The calculations originally contemplated by the writers and which it was proposed to carry out, were much more extensive than the ones embodied in this paper; the opinion at the time being that a solution might be effected on the following line of thought. The actual dam is composed of a succession of vertical elements or beams of varying hight, and of arched layers of differing length and included central angle. As regards the former, it is a very simple matter, having once determined the deflections for the unsupported elastic beam of greatest height, to determine from it the form of any similar beam of lesser height, or more correctly expressed, the form of a portion of the same beam, if shortened by the removal of a portion at its base. The general form of any curved layer would of course be determined less materially by the load at any particular point, than by the combined action of the load on the arch at all its points; its form in any case being a regular curve, more or less resembling that of the beam for a uniform law of loading. Now, any two curves, which generally closely agree with one another, but which leave a common tangent at the same point, will diverge from one another very nearly in direct proportion to the lengths of the arcs measured from the point of divergence. The vertical beams would follow some other law which would be, (apart from the checking influence of the curved layers), determined solely by the form of the cross-section of the cañon, and upon meeting with resistance from the arch springs would assume modified elastic forms; the adjusted mutual resistance exerted by the one system upon the other *at any point*, being the result of the sum of all the mutual interchanges of support exerted at all points, throughout the whole combined system. The curved layers would receive varying stress at different points of their arcs, or the law of their loading would

become unequal instead of uniform. They would assume new forms, probably determinable by calculation, the idea being that a method of "cut and trial" must eventually lead to a set of deflections which would be harmonious among themselves at all corresponding points of the two systems; the resistance requisite to produce harmony of deflection being a gauge of the stresses at all points of the dam.

This calculation would be purely analogous to the calculation which was made for the involute and the vertical beam, but of course much more extended and proportionately more complicated. The formulæ which would apply to such a case of irregular radial loads were actually deduced, when it became apparent that the first effect of unequal loading would be, that the rate of shortening of the arc would no longer be uniform throughout the length of any curved layer, but would be locally proportional to the load at the different portions of its length.

Now, for the Bear Valley Dam, the height of the dam proper (namely the portion above the base or pedestal) remains constant for fully half the length of the span, and as the offsets from the original curve to the deflected curve must decrease as we approach to the abutments, it follows that—at least between the crown and the "quarter points"—the rate of loading must *increase*, beyond which points it would follow some other law up to the abutments, where the arch must bear the whole water load; for here, although motion in the vertical fibers is conceivable, motion of the horizontal layers is not consistent with rigid fixture to the cañon sides. This idea of an irregular law of loading is graphically shown in Fig. 15 (left hand side).

The outcome of these conditions must necessarily be that for any given total shortening, the *rate* of compression must concentrate itself towards the quarter points and be less at the central section of the dam than for uniform loads. Hence, under the conception of resistances proportionate to the compression produced in the arch, there would be *less* resistance to deflection *at* the central sections than our previous calculations showed.

Now, what are the facts in the case? The quantity of masonry in the dam and so-called foundations is very nearly 2,900 cubic yards, and we are told that 1,700 bbls. of cement (say 0.58 bbls. per cubic yard) were used in the dam.

Making all allowance for probable differences in the character of the work, and taking the Sweet Water Dam experience of very nearly 1 bbl. of cement to the yard of masonry (with a ruling proportion of 1 cement to 3 sand), we infer that probably in the Bear Valley Dam the mortar did not vary much in richness from that ratio. Now, taking the excellent data relative to cement tests contained in Mr. E. C. Clarke's paper, read before the American Society, April, 1885 (see also Boston Main Drainage Report, Appendix A), we find a value of 217 lbs. per square inch, as the tensile strength of mortar of this degree of richness twelve months old, taken from a table which was compiled from about 25,000 breakings of briquettes.

Now, it will be generally granted that mortar, under the conditions in which it is used in actual work, will show a materially smaller tensile strength than that given by test briquettes, if for no other reason, that the pressure under which mortar sets materially affects its strength after it has hardened, partial air drying—as distinguished from setting—and unevenness of mixture being other features more or less unavoidable in actual work. Now, taking Mr. Clarke's average value as a probable outside value for the tensile strength of the mortar, and comparing it with the theoretical tensile strain at the bottom of the dam (327.1 lbs. per square inch)—this value having already been reduced for the probable influence of arch action, on what we believe a very liberal basis—the latter figure is 1.65 times what we are warranted in assuming as the ultimate strength of the mortar. From this we believe that it is a justifiable inference, that were the strains really taken up in the manner which is pretty generally supposed,—and in the way treated of in the preceding investigations—rupture of the masonry would be an unavoidable result.

A beam in the condition of that shown on sheet 2, with the line of strain such is there shown, must inevitably be totally ruptured at the base and overturned. However in the case of its being a portion of a curved dam, total destruction does not by any means follow as a foregone conclusion. On the water side, joints might open where the tensile strain was excessive; as a result of which, more load would be thrown upon the arch, and provided the arch layers were capable by themselves of bearing

the additional load, nothing more serious than a slightly opened crack would ensue. As regards the capacity of the arch layers in the Bear Valley Dam to really sustain the water pressure acting on the dam, and to *transfer it entirely to the abutments* if called upon to do so (provided the layers were brought into a condition to assume the strains), we give in the following table the pressure in tons of 2,240 lbs. per square foot, which the "arch pressure" formula would give as a duty for the masonry in the different layers, together with the ratios which these strains bear to the commonly permitted strain of 14 tons. The table gives the water load at each section, and the uniform load q required to produce a crown deflection of 1″, estimated on a basis of E = 1,500,000 lbs. per square inch; from which we give in the following columns, for each curved layer of the dam, the requisite deflection of the beam, in order for it to support the load resting upon it—provided the layer be equal to the task—using the same value for the modulus E. The last column gives the required crown deflection taking E = 4,500,000 lbs., which we believe to be at any rate of sufficiently high value for masonry such as is before us.

1	2	3	4	5	6	7	8
Section	Depth in feet.	Arch pressure; tons per sq. ft., by formula $s = \frac{qR}{t}$	Ratio of arch pressure to permissible pressure of 14 tons.	Water pressure in lbs. per sq. ft. of dam face.	Spring (beam) resistance for a crown deflection of 1. inch.	Crown deflection required by beam, in order to assume given load.	Crown deflection, using a modulus of 4,500,000 lbs.
					For E = 1,500,000 lbs. per sq. inch.		
1	4.3	9.56	0.68	269	364	0.74	0.25
2	8.6	17.15	1.22	538	406	1.33	0.44
3	12.9	23.34	1.67	806	452	1.79	0.60
4	17.2	28.52	2.03	1075	497	2.16	0.72
5	21.5	32.85	2.34	1344	543	2.48	0.83
6	25.8	36.54	2.61	1612	701	2.30	0.77
7	30.1	39.75	2.84	1881	780	2.41	0.80
8	34.4	42.59	3.04	2150	1608	1.34	0.45
9	38.7	45.04	3.22	2419	1846	1.32	0.44
10	43.0	47.23	3.37	2688	2037	1.32	0.44

As far as the values in this table go (see column 3), the requisite pressures would appear well within the probable capacity of the masonry to withstand them, even though they are several times greater than what is usually sanctioned by conservative practice. However, the absolute crushing loads for stone are very high, and provided the dam were free to take such deflections as our last columns show, it might appear as though the dam might really be carrying its load as an arch, even though heavily taxed in so doing. If, however, instead of using the ordinary formula, we draw to our aid formulas 33 and 34, no very elaborate calculation is required to show quite different results. We have selected sections 5, 7 and 10, and assuming them to act as curved beams one foot high, deflected to the extent given in the table (using column 7 or column 8, and whether column 7 or 8 be used is immaterial), we give the values of the modifying elements M and H_1, due to elasticity, together with the strains which would result at the abutments and the crown, on both faces of the wall. They are as follows:

Section.....	Moment M in foot pounds.	Corrective Force H_1 (lbs.)	ABUTMENTS.			CROWN.	
			Extrados Line	Intrados Line.		Extrados Line.	Intrados Line.
			Pounds per sq. inch tensile strain.	Eccentricity of line of strain from middle of section; feet.	Pressure (tons per sq. foot).	Pressure (tons per sq. foot).	Tensile strain (pounds per sq. inch).
5	429100	27165	—2.55	1.01	60.76	44.06	—241.6=15.53 tons per sq. ft.
7	1327000	174660	+ 654.8	2.88	211 After joint opens on water side.	63.40	+ 97.0
10	2399000	614900	+ 1145.0	8.10	Indefinite; failure certain.	44.54	+ 228.4

It will be seen that instead of having to deal with purely compressive strains, serious tensile strains would be caused, not only at the abutments but at the crown also, and that the compressive strains are much greater than those first calculated. The three sections which we have considered, will in general

fairly represent the conditions for the other seven sections (which all agree in length of span with one or the other of the three sections given). As the line of pressure for sections 8, 9 and 10 would be outside the wall at the abutment, these would fail directly under the tensile strain on the water side, at the abutment, (see table); sections 6 and 7 would probably by themselves not be able to sustain their load, and would certainly fail after failure of the sections below them; section 5, and the sections above it, while probably able to support the load properly coming to them, would still not be able to withstand that brought upon them after failure of the sections beneath them. These figures lead to the conclusion, that even were the first effect of primary failure of the dam (by reason of the opening of horizontal cracks near the base), to go to the full extent of allowing the base to free itself from its foundations, and to slide into the form required for it to act as a horizontal arch, that it would still not be able to sustain the water pressure acting upon it, and that total destruction would result.

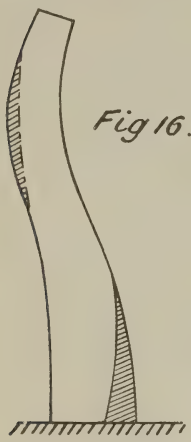


Fig 16.

One other possibility presents itself. Supposing the tensile strain at the base of the wall for a certain distance above its base, to be greater than the mortar could withstand, and that cracks were to open in the joints to a depth indicated by the shaded portion of Fig. 16, without the masonry pulling itself completely from its foundatians at the toe; that by reason of the opening of these joints, greater strains were thrown upon the arch, without the supporting action of the vertical fibers being destroyed, further than were necessary to afford relief to the tensile strain where too great: the case before us then would be that of an elastic beam, *hinged* at its base, and supported by springs similar to the case in the original calculations. It would be quite possible to determine the form which the beam would assume, and the relative proportion of arch relief for this case, even were we in the prosecution of the in-

quiry to be brought to the necessity of assuming for a certain part of the wall, that other joints were to open on the down stream side, as indicated in the sketch, which is of course much exaggerated in Fig. 16.

It is very questionable whether an adjustment could be arrived at, which would bring the strains within the limits which we could reasonably expect the masonry to withstand; certain it is, however, that we should be led to very considerable deflections, and to assumptions of the existence of cracks and incipient failures which nothing in the present condition of the Bear Valley Dam would warrant us in believing fulfilled. Like the other attempted explanations, we should be led to reject it as inconsistent and incorrect.

The calculations which have been so far made, pretty well cover the treatment of this remarkable dam, both from the "gravity" and the "hoop compression" standpoints, as well as the reasonable combinations which can be imagined as taking place between the two modes of operation; yet the results are purely negative ones. The conception has been all along that the dam was composed of two sets of elements, each of which presented a certain capacity for resistance; the aim of the calculation being to establish the proper relation existing between the two, and to determine the extent to which the one system might aid the other. As far as we know, this is the only standpoint from which the subject has yet been considered. We believe, however, that there is quite a different manner in which the strains may be taken up by the dam, and which will be worth the labor of inquiring into, even though the result be only an explanation by analogy and not a strict mathematical determination. The outcome may or may not lead to results which may be made the basis of calculation in future practice, but which will still not be devoid of interest, provided the conclusions are capable of verification by measurement of the actual deflections produced in the dam. Should these measurements correspond with the predicted values to within reasonable limits, then an inference may probably be made as to the extent to which the remarkable performance of the Bear Valley Dam

may warrant the expectation of a corresponding duty, in structures built under different conditions. Without some such measure, the record of the Bear Valley Dam will remain that of an isolated case, contributing but little to a knowledge of a subject of evident practical value.

As the treatment is one which differs from any method yet followed, and a proper spirit of conservatism might object to novel methods, unless upon sufficient proof that customary treatment fails to reconcile fact with theory, we have not been deterred from adhering to the extended form in which our preceding calculations have been given, even though the result fell confessedly short of a solution of the problem. Another excuse for considerable detail lay in the fact, that we believed ourselves on unexplored ground, and feared to sacrifice clearness by too much curtailment.

We propose now to cast aside the idea of separate elements and to treat the curved structure as a whole body, independent of the separate movements of its parts.

Before doing this, however, we append in the briefest manner the results of some calculations made with reference to the Sweet Water Dam, which show in a general way, to what conclusions an inquiry similar to the preceding one would lead, if applied to a structure more nearly in accord with approved practice as heretofore accepted. Our figures are to some extent approximate, but not far from exact.

FIGURES FOR SWEET WATER DAM.

Maximum moment (at 80 foot depth)	4,428,800	foot-pounds
Moment taken up by arch resistance at same depth (involute formla)	542,700	" "
Moment, relieved by arch resistance	3,886,100	" "

Percentage of arch relief 12¼%.

[For E = 2,000,000 lbs., a top deflection of 0.0952 inch (unsupported) and 0.0767 inch (corrected for arch resistance).]

UNSUPPORTED SECTION.

Uncompensated bending strain	114.75	lbs. per sq. inch
Distributed weight and vertical water pressure	56.62	" " "
Maximum tensile strain	58.13	" " "
Toe pressure	171.37	lbs. per in. (11.02 tons per sq. ft.)
Eccentricity of line of pressure	13,54	feet
Distance outside ⅓ of wall	6.86	"

WITH ARCH RELIEF.

Uncompensated bending strain, central section—relieved by arch resistance	107.1 lbs. per sq. inch
Greatest tensile strain	44.1 " " "
Greatest toe pressure	144.8 lbs. per inch (9.31 tons per square foot)
Eccentricity of line of pressure	11.80 feet
Distance outside inner $\frac{1}{3}$ of wall	5.20 "

NOTE.—By the treatment hereafter following, there would be no tensile strains in the Sweet Water Dam.

SECOND METHOD OF TREATMENT.

Consideration of the Strains in an Elastic Cylindrical Body, Rigidly Fixed at Its Base.

In treating of the strains in curved dams in the method now contemplated, it is expedient not to deal directly with the dam as it actually exists—namely a body of varying height, supported at its ends by the abutting cañon sides, but to first consider the case of a dam of uniform height, and to disregard entirely the effect of resistances furnished by its side walls. Such a dam would evidently be a partial hollow cylinder, and may be regarded as a beam, loaded with a water load and rigidly fixed at its base. We propose to determine the form of the elastic line and to establish the strains which would arise; having done which, we will consider what modifications would result by changing the shape of its base to conform to the actual condition of an irregular bed, and also to see what the influence of side wall reactions would be. The radially acting forces which constitute its load may evidently be resolved into two components; one set normal to the chord, and the other parallel to the same, and these, for brevity, we will henceforth style respectively as axial and lateral forces. If R represent the radius to the water face at any layer, and α denote the half central angle subtended by the chord, then the axial force will be the projection of the load upon the chord, and will be $2q\mathrm{R}\sin\alpha$; the lateral force, similarly, will be the projection of the load upon the versed sine of the

arc, or $q\mathrm{R}(1 - \cos a)$, q being as heretofore the load per square foot upon the dam face, and of course a quantity varying with the depth of water for each curved layer of the beam.

The lateral forces counterbalance one another, and except as regards producing internal strains in the beam, (which will be considered hereafter), do not affect the general conditions of equilibrium, nor the shape of the elastic line, and may be disregarded.

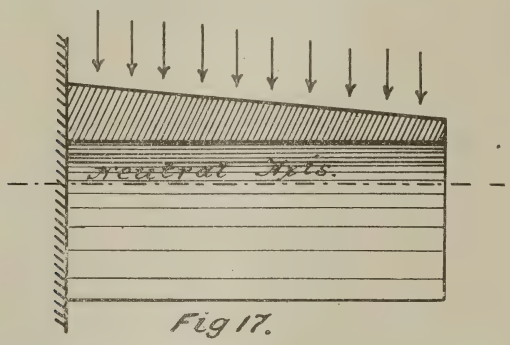


Fig 17.

For the present, considering the axial forces only, the dam may be regarded in the condition shown in Fig. 17. The position of the neutral axis is determined by the center of gravity of each curved layer, and the elastic line is again determinable by the formula

$$\frac{1}{\rho} = \frac{\mathrm{M}}{\mathrm{ET}}$$

where all the quantities have the former signification; M, however, now representing the moment of all the forces which act upon the whole width of span, instead of for a width of one foot, hence equal $\frac{1}{6}\gamma h^3$ multiplied by the span (h being the depth below the water surface), and T now standing for the moment of inertia of the whole curved layer, for an axis passing through the center of gravity, and parallel to the chord.

Let Fig. 18 represent any curved layer (or ring sector). Then if R and r represent the inner and outer radii respectively,

the area of the ring sector will be $(R^2 - r^2)a$, and the distance $OC = x =$ distance of the center of gravity from the center of the circle, will be

$$x = \frac{2(R^3 - r^3)\sin a}{3(R^2 - r^2)a}$$

and the moment of inertia for the axis YY,

$$T = \tfrac{1}{4}(R^4 - r^4)\,(\tfrac{1}{2}\sin 2a + a) - \frac{4(R^3 - r^3)^2 \sin^2 a}{9(R^2 - r^2)a}$$

For a modulus $E = 144 \times 1{,}500{,}000 = 216{,}000{,}000$ pounds per square foot, the deflections of the elastic line are as shown in

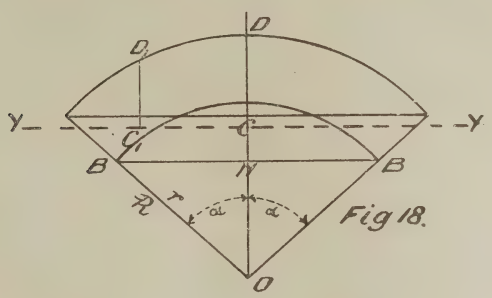


Fig 18.

table 2, column 7. The bending strains given in columns 10 and 11, are obtained from the ordinary formula $\frac{s}{w}T = M$, by inserting for w the proper values for CN and CD (Fig. 18). Col. 12 gives the effect of the equally distributed influence of the weight of masonry and vertical water pressure on the face of the dam, after applying which to columns 10 and 11, the actual maxima strains at D and B are obtain, as given in columns 13, 14 and 15.

BEAR VALLEY DAM. TABLE 2.
Showing the Main Elements of Calculation by Method II.

1	2	3	4	4½	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Section.....	Inner Radius, r.....	t Width of Wall in feet	Outer Radius, R.....	x = distance of center of Gravity from center of Circle ...	Moment of Inertia of Surface. (Ring Sector.)	Moment of External Force M (on 1 foot length of Beam).....	Deflections of the Elastic Line of Unsupported beam in $\frac{1}{1000}$ th inches..	w_1 = CN = (x—312.22).....	w_2 = CD = (R—x).....	Bending Strain: At B (Pounds per sq. inch.)	Bending Strain: At D (Pounds per sq. inch.)	Correction for Weight and Vertical Water Pressure..	Corrected Pressure at B.: Pounds per sq. inch.....	Corrected Pressure at B.: Tons per sq. foot.....	Corrected Strain at D. Lbs. per sq. inch.....	Spring Beam forces for 1 inch deflection, lbs. per sq. foot.....	Resistance corresponding to deflections in Col. 7. Lbs. per sq. foot.....	Moment of spring resistances corresponding to Col. 17....
0	335	3.72	338.72	329.20	44464	0	46.786	16.98	9.52	0	0	0	0	0	0	320.59	15.0	0
1	"	4.20	339.20	329.43	50573	827	40.6588	17.21	9.77	0.49	0.28	4.6	5.09	0.33	—4.32	363.95	14.8	140
2	"	4.68	339.68	329.66	56894	6615	34.5478	17.44	10.02	3.50	2.01	9.0	12.50	0.80	—6.99	406.49	14.0	560
3	"	5.16	340.16	329.90	63440	22326	28.4940	17.68	10.26	10.76	6.25	13.2	23.96	1.54	—6.95	452.43	12 9	1220
4	"	5.63	340.63	330.13	69914	52920	22.5756	17.91	10.50	23.44	13.74	17.1	40.54	2.61	—3.36	496.87	11.2	2110
5	"	6.11	341.11	330.37	76672	103359	16.9142	18.15	10.74	42.31	25.03	21.0	63.31	4.07	+4.03	543.41	9 2	3230
6	"	6.59	341.59	330.60	83690	178604	11 6780	18.38	10.99	67.81	40.55	24.8	92.61	5.95	+15.75	584.87	6.8	4510
7	"	7.07	342.07	330.84	90855	283617	7.0750	18 62	11.23	100.5	60.56	28.6	129.1	8.30	+31.96	627.54	4.4	5900
8	"	7.54	342.54	331.07	98035	423358	3.3720	18.85	11.47	140.8	87.63	32.3	173.1	11.13	+55.33	669.20	2.25	7390
9	"	8.02	343.02	331 32	105818	602790	.8921	19.10	11.70	188.1	117.7	36.0	224.1	14.40	+81.70	711.87	0.63	8910
10	"	8.50	343.50	331.545	113615	826870	0.	19.33	11.95	243.6	150.5	39.6	283.2	18.21	+110.90	754.43	0.	10470

It may appear that these values for the magnitude of the strains are valueless, on account of the resistances of the abutments or side walls which must always exist in practice; that they would not permit the fibres in our vertical beam to conform to the elastic line which we have calculated for the beam, and that they will therefore not be able to take up the load in the way we assume it to be taken up. This would be wholly true if the arch were a rigid body, and it is true to a certain extent for an arch of compressible material; but in as much as it is true, the only effect of the abutment resistances will clearly be to reduce the calculated strains by a certain amount, thereby assisting the vertical fibres and relieving them of a portion of their strains. Under the influence of the water load, distortions will be produced in the curved layers of the beam, and this distortion will extend to the point (and only to the point) where the deflections are such, that the vertical fibres have been sufficiently stretched to take up the residual load not expended in compressing the curved layers.

The arch layers act entirely as resisting springs, and the stiffness of these springs for any amount of deflection, is an already known quantity. Column 16 gives the resistances for a one inch crown deflection.*

Column 17 gives the values of q, which correspond to the deflections given in column 7 for the vertical beam, and column 18 gives the resisting moments which these forces would exert at each of the ten sections of the dam. The general manner in which these values of q might be used to determine the real adjustment of the load, as distributed between the arch fibres, and vertical fibres of the dam, should be sufficiently clear from our earlier calculations. However, by inspecting columns 17 and

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*For the five lower sections—6 to 10 inclusive—the values given, are the involute values, increased by 12 per cent. This assumption is a sufficiently correct one, as it was shown in the table on page 124 that the ratio of the beam resistance to the involute resistances, is practically constant, as long as α remains the same, that is to say, of course, if R and t change but slightly, as is here the case. This assumption of the values q_6 to q_{10} was made solely to save a rather extended calculation, the result of which could be very closely foretold, and is especially warranted where close results are immaterial to us.

18, and bearing in mind that they are approximate values, and about 33% to 50% greater than what they would be after adjustment, we see that, in the case of the Bear Valley Dam, they amount to nothing as compared with the moments exerted by the water pressure (see column 6), and that they would modify the strains given in columns 12, 13 and 14 only to an insignificant extent. In our dam therefore (we do not say in any dam) it appears that the strains would be just about the same, whether side wall resistances were present or not. The results of this calculation are already much more satisfactory than those deduced from any previous treatment, and they will be all the more so, when it is considered that the values for the tensile strains at D are the maxima values occurring anywhere in the dam; that for any other point D_1, the *bending strain* would be less in proportion as D_1C_1 is less than DC; that is to say, in proportion as its distance from the neutral axis YY decreases. The absolute strain at D_1 will however be decreased to a still larger degree than is expressed by the foregoing ratio, as the evenly distributed influence of weight of masonry and vertical water pressure (see column 12) is the same for any point in the section. However, 110.9 pounds per square inch is not so high a value that we need be surprised at ordinary good cement mortar sustaining it, especially when the maximum value, as has been stated, is confined to a very small area.

We will next consider what change will be produced in the strains by an irregular foundation line, as formed by the bedrock profile of the cañon. This case may be referred to the preceding one, by imagining a portion of the cylinder encased in the side walls of the dam site.

Let Fig. 19 represent any fixed beam, acted upon by forces as shown, and brought under strain by its load. Now suppose that along the irregular line *ab*, the shaded portion of the beam were built in with solid masonry; no change would occur in the strains at any point, neither within the shaded portion nor without the same. Were the shaded portion encased in its envelope prior to the application of its load, however, then the change in the strains would depend entirely upon the compressibility of the envelop, both as determined by its mass, and

by its degree of elasticity. As an extreme case, let the envelop be regarded as absolutely rigid, and the shaded portion of the figure now forming a part of it. What is the result?

Between the free end of the beam and the section AK, none of the conditions are altered, hence the strains remain as before. For the part of the beam beyond AK, the load resting upon it now goes direct to the shaded figure, and produces no strain in the horizontal fibres; hence the strain in the most remote fibre AN_1 can at no point increase beyond the maximum value at A. The portion of the line between O and N ceases to be a neutral axis, as owing to the incompressible nature of the part of the figure assumed to be rigid, the fibres can no longer adapt themselves to assume strains conformable to this line as a neutral fibre—the tendency evidently being to bring about an

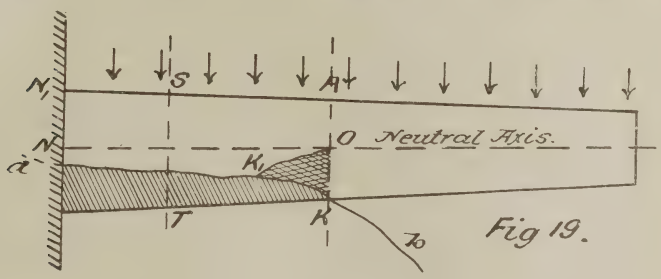


Fig 19.

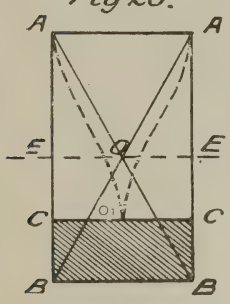
adjustment such that for any section ST, the strains will equalize themselves as much as possible and all become alike in nature; that is, all become tensile strains in this case. For, were the fiber strains, as transferred from the plane AK to the plane next back of it, to go on unchanged in magnitude in each fiber as far as the base NN_1, different changes in length in differently strained fibers must result, from which would follow deflections in the beam which the rigid envelop could not conform to, and which it would prevent. It is of course well known that between adjacent and contiguous fibers strains exist, as well as in the fibers themselves; that these strains are of a shearing nature, and that their function is to prevent slipping of one fiber along its neighbor; as a general principle the shearing strain in the direction of the

strained fibers, being greatest where the fiber strain or bending strain is least.

As a consequence of this general principle of strained bodies, a certain zone must extend back of OK to some point K_1 on the confines of the shaded figure, such that an irregular line OK_1 will be a neutral line of strain; on the one side of which (within the space OK_1K, shown in cross shaded lines) compressive strains only, on the other side of which, tensile strains only will be found.

The location of the point K_1 and the nature of the line OK_1 would, of course, depend purely upon the special conditions of the case.

Fig 20.



For a section ST, let Fig. 20 represent its cross-section; AABB being the original section, CCBB the portion afterwards considered rigidly enveloped, EE the original natural fiber of the section and *b* the width AA or BB of the section. Under the original conditions, the widths of the triangular figure AAO, gave the law by which the fiber strains varied from zero in the neutral axis to the maximum value *s* in the outermost fiber AA. After encasement in the envelop, assuming O_1 to be the neutral point, the irregular dotted figure AAO_1 may represent the law of change of fiber strain. The areas of AAO and AAO_1 may be said to represent the capacity for uniform strain resistances in each case; and if we assume equal external stress to act on the section under both conditions, the maximum strain in the fiber AA would be less after the introduction of the rigid zone CCBB than it was originally, in proportion as the triangular area is less than that of the irregular figure AAO_1.

In seeking to apply these deductions to the case of a beam whose cross-section is composed of curved layers, the terminals of which alone join the rigid envelop (or cañon profile) and whose intermediate points are unsupported—the forces shown in Fig. 19 as working on the layers between A and N_1, only go partially to the envelop, but pass mainly from curved layer to

curved layer, until finally transferred to the base. The effect upon a section ST, however, is that the moment at that section is reduced below what it would be, were the beam of constant span; first on account of the partial transference to the abutments which has been noticed, and also on account of the contraction of the surface exposed to the water load;—from both of which causes follows a reduction in the maximum strain below the value which is given for the strain in table 2.

With this result we must rest content, and the result would really be a satisfactory one, were it not that we have assumed conditions which it is easy to show cannot be strictly fulfilled.

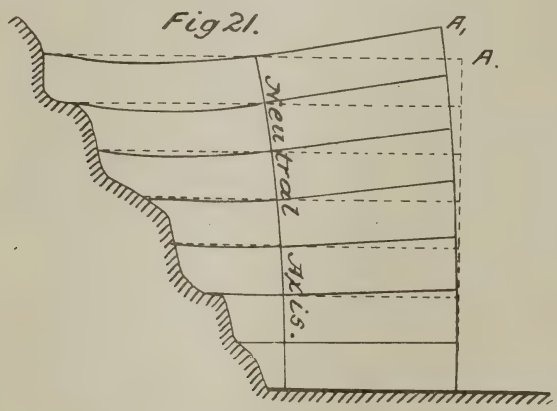
The thorough freedom of all fibers to accommodate themselves to the strain brought upon them by the load, which exists in a free beam, is here interfered with by the fact that the fibers at their junction with the presupposedly rigid abutments, are not free to slide along their lines of contact.

The effect of this is again to interpose a resistance to deflection, and as such it *probably* would tend to still further oppose the generation of tensile strains near the crown. Nevertheless, this effect is produced by resistances which are not contemplated in the assumptions underlying the beam theory; from which results an uncertainty as to the distribution of the actual strains in the section, which should be borne in mind. We have not, however, sought to determine the actual strains in the dam, but only to determine an outside limit, which the values of the actual strains would not exceed, provided that the action of the dam in general, accords with the assumed hypothesis.

We cannot assume, what is assumed for the beam under transverse loads, that the particles which lay in the same cross-section, or horizontal layer of the dam, remain in *plane* surfaces after the dam is subjected to load, but we can conceive them to lie in *curved* surfaces, which are horizontal crosswise with the cañon—so that layers which in Fig. 21 were originally straight, as shown by dotted lines, become subsequently curved, as is indicated by the full lines. Such a condition is quite compatible with the general assumptions made in the case to which we have endeavored to refer the actual one before us. It is quite conceivable that in general the transference of the load takes

place actually, from layer to layer to the base, though partly modified by a portion of the same passing to the abutments in an arch sense, and also that another portion finds its way to the abutments through the resistances which the latter offer to vertical sliding of the masonry along the abutting faces; whereby a *reduction* of the strains is caused below the values which they would assume, were the latter resistances not present.

As regards the probable nature of the curved surfaces which would be formed, it would be useless to speculate upon them as a means of deducing the actual value of the maxima strains. The actual deflections imparted to the dam, under varying heights of water surface are the only means of gaining a knowledge of the actual strains, as they are also the only means of determining whether our hypothesis as to the manner in which action takes place, is a warrantable one.



The mere fact that our calculations lead to strains which would be quite within the capacity of the masonry to withstand, is no conclusive proof that action takes place in the manner we have assumed it to take place. All that can be said in its favor, is that this treatment suggests a probable explanation, consistent with known principles of mechanics, while no other hypothesis which has yet been suggested, appears to have done as much.

Now the point to be determined by measurements is this. If we are to explain the action of the dam, as being similar to that assumed in our first calculations, then we are to expect deflections of considerable magnitude, measurably corresponding at the middle of the dam with the values given in Table 1—though probably larger than those values, for several reasons which should be apparent—and of such a nature that at any point on the crest of the dam, *the direction of greatest deflection should coincide with the radial line drawn to the center of curvature;* whereas, if the action of the dam corresponds to our second hypothesis, then we are to expect deflections whose absolute amounts are very small quantities (less than those given in Table 2), changing less rapidly relatively speaking from the center of the dam towards the abutments, and always of such a nature that at any point along the crest of the dam, *the direction of maximum change will be in a line parallel to the axis of the cañon*, that is to say parallel to the radial line at the middle point of the dam—while the direction of least deflection will be at right angles to the last.

How such measurements are to be best conducted, is a matter worthy of consideration by the society. It appears to the writers that the crown deflection might best be measured by transit observations from the bank, by which the absolute value of the movement there, might be obtained with very considerable accuracy; that at other points simple level bubbles set in boxes with carefully ground beds, to rest freely on ground bed plates which have previously been rigidly attached, in a horizontal position, to the masonry of the dam, may be simple, accurate and inexpensive means of determining the angular changes arising from deflections of the structure. The levels being free to be placed in any vertical plane, the direction of maximum dip would be easily ascertained.*

The Bear Valley Dam is to be superseded by another dam, which is to be of gravity section, built upon a curve, and located some eighty feet lower down the cañon than the present dam.

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*Of course, the correct value of the modulus would have to be determined, where absolute values of the deflections are desired. The values in Tables 1 and 2 are only supposed to be relatively correct for E = 1,500,000.

As this structure rises in height, water is to be let in between the two structures, in order to relieve the present dam from strain. There will evidently arrive a time in which a series of measurements could be made upon the dam, under almost any desired conditions of loading, without loss of water and with but little lapse of time intervening between the measurements. Another opportunity to obtain by experiment such insight into the real conditions of strain in masonry dams, may possibly never occur again, nor is it probable that any structure will be built whose testimony would be of greater value, nor likely to settle more points of controversy, than this special dam, if conscientiously studied.

The interest is not local, but of general significance, and we suggest it, as a suitable subject for the endeavors of the Society, to take the investigation under its auspices as a body, communicating with other societies relative to the best method of obtaining the results, and rendering them valuable when obtained; more especially, however, with a view to collecting data by similar observations made on other dams, when favorable opportunity for observation is presented.

Material might possibly be thus collected for accurate determination of the strain in curved dams, which as a purely theoretical problem is probably not capable of exact solution. Even if no such unequivocal conclusions were reached, if we obtain results approximately agreeing with deflections such as our theory would require, the outcome would still not be other than valuable. The internal strains (shearing and normal) at all points and in all directions, are determinable quantities for the unsupported hollow beam under transverse loads. Where only a general conformity with the hypothesis established, a substitution of an ideal structure of uniform height, such as was used in our calculation, could be made in any particular case, with the assurance that the strains in the actual structure would *not exceed* those determinable for the supposititious one, in which the auxiliary influence of side support and irregular foundation were neglected. A determination of the maxima internal strains for this case would probably give a *safe*, though not a *correct*,

gauge of the extent to which the performance of the Bear Valley Dam might be looked to as promising enhanced strains in curved dams, under other conditions.

The general impression of the writers is, that such an inquiry—provided we were restricted to a treatment by analogy, as just described—would point to a decreasing rate of efficiency of the curved over the straight type, with increasing lengths of dams; that cross-sections of very narrow widths would not be justifiable, provided due regard be paid to the possible values of the internal strains, which might be excessive even though the bending strains were not too great;—and that we should be led to ascribe the high duty of the Bear Valley Dam to a favorable combination of conditions, which would not have held good had the span been considerably longer than it is.

While it would probably be demonstrated that the curved type always possesses an advantage over the straight one, the curved form offering a certain resistance for quiescent water loads, which under sudden shocks or dynamic stress would increase with the load, still no such enhanced resistance in any case exists, as would be ascribed to the horizontal arch, if estimated by the formula $s = qR \div t$. In fact, were that formula a correct index of the strength of the arch (which we believe we have shown is not the case), then the superiority of the curved type over the straight, would need no further demonstration. For, were only compressive strains generated in the arch, as that formula would imply, then it is hardly possible to fix a strain so great, that in practice we need count upon destruction of any dam of reasonable radius; for, while it may be expedient in construction to limit the compressive strains to fourteen tons per square foot, still we know that often 600, and even 1000 tons fail to crush stone, when the conditions are favorable ones. The dam would probaby never fail through direct crushing of any part of the masonry, its destruction being brought about, under much lighter loads, by reason of cracks opening inside the structure, where the shearing strains became excessive, or where

the tensile bending strain exceeded the resistance of the masonry.*

Upon the other hand, provided the relief brought about through the curved plan, should prove to be a result of arch resistance only, (either compressive or beam resistance) as was first assumed, or should this part of the relief alone be capable of determination, and therefore alone be recognized as a measure of the extra security to be obtained by the use of curvature, then it would appear that the amount of relief to be anticipated from this source is largely dependent upon the choice of the radius of curvature.

Recalling our first calculations, the involute assumption, which probably fairly represents the influence of arch compression alone considered, would point to the selection of small radii, as a means of increasing the element of arch resistance; the subsequent investigation lead, however, (see table, page 124), to the conclusion that the true curve resistance to deflection materially increases with decreasing central angles; so that for constant radii and uniform dimensions of cross-section, the ratio of the curve resistance to arch compression resistance, is practically constant for any fixed value of the central angle. From this it would appear, that a *proper selection of the radius and the*

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*As regards the shearing strains in the ideal beam with unsupported sides (Fig. 17), the greatest shearing strain acting in the direction of the neutral axis, at the base of the beam, would be about 837 lbs. per sq. inch; compare Ritter, page 81, *et sequel.* The value designated as ε is 17.25 ft.; V=14,445,000 lbs.; and as the width of the section, measured parallel to the chord is 41.7 ft. on each side of the dam, the shearing strain p is

$$p = \frac{14,445,000}{83.4 \times 17.25 \times 12} = 836.74 \text{ lbs. per sq. inch.}$$

Prof. Heinzerling in his "Angreifende und Widerstehende Kraefte" gives 8 to 16 kilos. per square centimeter (*i. e.*, 114 to 228 lbs. per square inch) as a mean value of p for mortar, assuming tenfold safety. While the resistances due to side support of the cañon, etc., probably tend to prevent the shearing strains becoming as great as the above calculation would make them, still it is probable that very considerable shearing strains exist in the dam, leaving no considerable margin of safety, even though the strains be taken up according to the hypothesis we have suggested.

central angle, will lead to a maximum curve resistance, both considered as an absolute quantity, and economically considered with reference to the (slight) difference in amount of masonry involved in a choice between different curved projects.

As regards the extra amount of masonry required by the use of a curved plan, it is generally a very small quantity; much less than has been frequently assumed. Upon this point we speak advisedly, and after having had occasion to test the statement in connection with a number of dam sites. The difference is not usually 10 or 15 per cent., as has been suggested; 5 per cent. in almost any practical case allowing for very liberal curvature,—probably quite up to what would appear desirable in practice, with due regard to securing suitable abutting angles between the arch and the cañon walls.

For the Bear Valley Dam, the quantity of masonry in the present dam (not including the lower base), as nearly as can be estimated from the plans, is about 2019 cubic yards. Had the dam been straight, the quantity would have been 1986 cubic yards. A straight dam of equal height, constructed upon recognized principles, (excluding tensile strains in the dam), would have required about 4860 cubic yards. The use of curvature in the actual dam only increased the amount of masonry about $1\frac{2}{3}$ per cent., and the dam as constructed only consumed $41\frac{1}{2}$ per cent. of the masonry, which an orthodox "gravity" project would have required.

The most pronounced opponent to the use of curvature, would hardly assert that a straight dam of the same cross-section as the Bear Valley Dam, would have successfully resisted the load which a full reservoir would have subjected it to; and whatever the opinion as to the boldnesss of the design, its performance must be recognized, and its efficiency conceded as a result of the use of curvature, under conditions which entailed but slight additional cost.

The question of the curved versus straight type, has been considered upon rather narrow grounds, and personal bias has cut too large a figure in the matter. Arguments have been advanced on both sides which were not worth consideration.

As regards the simple nature and the thorough harmonious-

ness of the strains in straight dams, which has often been dwelt upon, it requires little consideration to see that in practice this simplicity does not exist. The claim of simplicity would really be correct, were the straight dam of uniform height and unresisted by fixture to the cañon sides. There can be no doubt, however, that a tendency to shear off the dam from its side-supports, always exists in the case of the straight dam (probably more so, than when the dam is curved) and it is only due to the very liberal dimensions used in practice, and the consequently small deflections, that the induced strains are not serious in nature. This suggests another advantage of the curved type; namely, that it is in a better condition to yield easily to the internal strains due to temperature changes than is the straight dam, which not being in a position to "buckle" must transfer all such strains directly to the abutments, so that working strains alternately tend to thrust the abutments outwards, or to tear the masonry loose from its side supports. Without wishing to attach undue importance to a matter which probably does not deserve very serious consideration, it must be admitted that technically considered, this is not a desirable feature of the straight type.

Apprehension has been expressed, that curvature introduced unknown elements into the problem, which have apparently been considered as entirely erratic in their action. This hardly needs a mathematical disproof. It appears almost a common sense proposition, that if a structure is precluded by its manner of construction from affording considerable arch relief, then the strains growing out of such action can be of no considerable magnitude. If a mathematical expression of this fact is desired, then formulas 33 and 34 may be offered in support of the proposition.

It would not be difficult to point out supplementary actions which probably take place in the curved structure, and which go to relieve the central section of a portion of its strains. These were omitted, as their joint effect would not have been sufficient to so materially affect the showing, as to reduce the strain to within limits which might explain the high resistance of the dam, and were omitted in order not to needlessly lengthen a paper already longer than was originally contemplated.

Without wishing to pass criticism upon a structure, whose phenomenal duty must be its best endorsement, it may be remarked that an addition of less than 10 per cent. to the quantity employed (namely, by modifying the section slightly, and selecting a radius more favorable to arch resistance), would have led to very different values for the theoretical strains, practically reducing them to within limits which need have caused no surprise at their having been withstood.

Had the Bear Valley Dam, however, been constructed in conformity with these changes, it would have been robbed of the interest which it possesses, as one of the most phenomenal structures ever designed and carried to a successful issue; one whose instructive lesson may first be completely understood, only after it has ceased to exist as a useful structure.

TECHNICAL SOCIETY OF THE PACIFIC COAST.

INSTITUTED APRIL, 1884.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

(VOLUME VI.—FEBRUARY, 1890.)

WHAT CONSTITUTES A MAP.

BY WM. G. RAYMOND, Mem. Tech. Soc. P. C.

[Read January 3, 1890.]

Maps are made for various purposes, some to show the outlines and main physical features of a continent or country; some to show the conformation of the surface of a continent or country; some to show the outlines of smaller districts or the conformation of their surfaces. Some are made to give information necessary to the correct planning of great works, such as railways, bridges, canals, mines, drainage and water supply systems, &c., and some are made for the purpose of serving as a basis for the description of lands to be conveyed from one party to another. What should appear on a map depends entirely on the object for which it is to be used, and at this time I propose to confine my attention to maps made to describe real property. Such maps are of cities, towns, or "additions" thereto, or of farms, or as we call them in California, "ranches," or other tracts of marketable land. It may seem at first thought that there is little to be said on such a subject, but when the fact, with which most of you are acquainted, that millions of dollars worth of property in this State depends for its correct location on some advertiser's printed circular, is fully realized, the possibility that all has not been said that might have been said suggests itself, and the question, "What constitutes a map?" becomes a pertinent one.

In our county records anything that is made up of lines and figures, either drawn by hand, photolithographed or simply printed with "rule" and type, and labeled "this is a map," is considered a sufficient basis for the correct description and location of the property it purports to represent.

Our records are full of auctioneers' circulars, manufactured in a printing office from information coming from nobody knows where, filed at the request of the auctioneer's clerk, with no name of owner or other interested party attached except as the name of the auctioneer appears in the accompanying advertisement.

Further than this, these maps are frequently, purposely distorted to create a favorable impression of the property to be sold. Wide streets are shown where only narrow ones exist, streets opened for the full width where they have been opened for but half their width, rectangular subdivisions that really may not be even parallelograms, &c., &c. Such maps as these frequently form the only basis for the description and location of the property they are supposed to represent.

This circular business is bad, *very* bad for those who buy; but is the information given by these circulars of much worse character than that furnished by many of the maps made by surveyors and filed at the request of the owners?

On these plats, if of "additions," we find lines indicating the boundaries of blocks and lots, all of which blocks and lots are numbered; the names of the streets appear in neat letters, a few dimensions, possibly all linear dimensions, will be given; the streets or blocks may be tinted with soft and delicate tints and the whole set off with an elegant border and title. As an exhibition of the draftsman's skill these maps are valuable. As a source of information as to the location of the lines they purport to show they are worth about as much as the auctioneer's circular. Perhaps they have a few more figures, and the presumption may be a little stronger that the figures are correct.

Examine one of the maps closely. You will find no evidence that a monument has been set in the field, not an angle recorded, though the lines may cross at all sorts of angles, and dimensions given that do not agree among themselves—so that it is impossible to "calculate" the angles.

You will find no name signed except, possibly, that of the surveyor, who thus advertises either his stupidity or something worse. Let us be kindly, and call it stupidity.

Frequently no monuments are set except small stakes at the corners of the blocks, but the fact that even such stakes have been set is not recorded on the plat.

One who is acquainted with the practice of surveyors in a given district, knows at what points to look for such stakes, and if they have been set and not pulled out to make room for a fence-post or building he may succeed in finding them. Some surveyors have a practice of setting stakes a certain distance away from the point the stake is supposed to mark, but no mention of this fact appears on the map. In fact the map is so drawn that no one but a surveyor who made it can write a correct description of any one of the parcels of land shown, nor correctly locate it on the ground. Furthermore, the surveyor himself finds it impossible, after the lapse of a few years and the destruction of his "private marks," to re-run any one of the lines exactly, as originally laid out.

It is easy to see to what this leads; impossible descriptions of property giving opportunity for differences in judgment as to interpretation of what was intended; disputes as to position of party lines; costly litigation and expensive movement of structures begun or completed, and the actual shifting of lines back and forth by different surveyors or even the same surveyor, honestly trying to locate the lines properly.

The writer has seen enough of trouble of this sort to indicate to him that a radical change is needed in the field work and mapping of cities, towns, and additions, not to mention farms and other tracts of land that it may be necessary to lay out and describe.

So long as fallible man is responsible for the accuracy of surveys, maps and descriptions of properties, so long will there be errors; but that it is possible to greatly reduce their number by proper regulation, the writer is fully persuaded. What we have been describing are not maps at all, or at most they are very imperfect maps, and "What constitutes a map?" thus seems to be a perfectly proper question.

A map of a city, town, or addition, or other tract of land, serving as the basis for the description of property, should furnish all the information necessary to the proper description and location of the various parcels shown, and also of the whole piece. It should also show the exact relation of the whole tract to the lands immediately adjoining; particularly should this be done when an offset or angle is made in the line of any street. To accomplish these things the map should give the following facts:

1. The lengths of all lines shown.
2. The exact angle between all intersecting lines.
3. The exact position and character of all monuments set.
4. The numbers of blocks and lots.
5. The names of all streets, streams or bodies of water or recognized landmarks.
6. The scale.
7. The direction of the meridian.
8. The angles of intersection of the lines of adjoining property, with the boundaries of the tract mapped.
9. The exact amount of offset—either nothing or some definite quantity—made in lines that are carried from the outside through the tract mapped.
10. A simple, complete and explicit title.

Thus much to make the map valuable for description and location of the property it shows.

Of course monuments will not be shown if none have been set, and very frequently none are set, either from carelessness on the part of the surveyor or an unwillingness on the part of the owner to pay their cost. Monuments of a permanent character should be set at each corner of a tract surveyed, and at least two, visible the one from the other, on the line of each street. If these monuments are not placed on the center lines of the streets they should be placed on lines a uniform distance from the center; so far East or West on North and South streets, and so far North or South on East and West streets. The stakes or monuments set at the corners of the blocks in additions or town sites should never be the *only* stakes or monuments set in the tract.

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That the map may be reliable there should appear on it the following:

1. The certificate of the surveyor that he has carefully surveyed the land, that the map is a correct representation of the tract, and that he has set monuments (to be described) at the points indicated on the map.

2. The acknowledged signature of all persons possessing title to any of the land shown in the tract, and if possible those of adjoining owners.

3. If of an addition, the acknowledged dedication to public use forever of all areas shown as streets or roads.

4. If a street of full width, whose center line is a boundary of the tract is shown, the acknowledged signature of the owner of the adjoining property, unless his half of the street has been previously dedicated.

As I have already stated, a map may be filed at the request of any person, and without signature.

This practice frequently leads to trouble. The writer knows of cases in which owners of large tracts of land have had those tracts subdivided and have taken land of adjoining non-resident owners for street purposes without the consent or knowledge of those owners. When at a later day the owners of the land so taken have objected and attempted to close half of the street, trouble of a serious character has arisen. The same thing has occurred where streets have been run through narrow gores of land and have subsequently been completely closed, leaving houses built on the mapped property without outlet. Time and again have cases of this sort come to the knowledge of the writer.

It is an easy thing to criticise but quite another thing to point out a remedy, but there is a saying that one should not offer criticism unless he is able to better the thing criticised.

Therefore, having pointed out certain evils it remains to suggest the remedy. It lies in the enactment of a law governing these matters. There should appear on the statutes of the State a law defining explicitly what shall appear on every map filed for reference, and making it a misdemeanor to file a map that does not strictly conform to the definition. I have thought

that it would be eminently proper for this society to take the initiative in the matter of securing such a law. A committee of this body might be appointed which, acting with a committee of our law-makers or a committee of the members of the bar or simply by securing legal advice in the matter, might frame an act, having for its object the reformation of the evils that have been pointed out, to be offered for passage at the next session of the legislature. There are other matters, in relation to municipal work that need correction, and at some future time I may speak of the proper time and method for doing various kinds of city surveying, of the arbitrary way in which some surveyors fix and change and fix again the recognized lines and grades of public streets, of the destruction of monuments, of the necessity for the complete resurvey and mapping of many of our towns and cities, of the question "Why is the information as to public lines and monuments obtained by the surveyor, while in the employ of the public, any more his private property than the public records in the office of the Clerk, or Auditor, or Recorder are the property of the individuals holding those offices during the time those records were made?" But one thing at a time. This question of the proper making and filing of maps, seems to me one demanding immediate attention while our State is yet young. Is it not worthy our careful consideration?

DISCUSSION.

Mr. Molera—(Occupying the Chair)—I was not aware that anybody could file a map for record in the public records.

Mr. Raymond—I do not know what the law is on the matter; I only know the fact exists.

Mr. Molera—Mr. Raymond, will you make a motion that a committee such as you suggest, be appointed?

Mr. Raymond—I move that a committee be appointed to consider the preparing of an act to regulate the filing of maps.

The motion was seconded.

Mr. Vischer—Professor Raymond's paper calls attention to facts which undoubtedly exist. It may be well for the society

to emphasize the fact of their existence, but I fear that it will be almost impossible to bring about a substantial improvement.

The difficulty lies not with the surveyors, but with the public, I think. I have generally found owners tolerably indifferent whether a map or a deed represent property exactly or not, as long as immediate inconvenience is not felt; that, unless in case of serious discrepancies, they are willing enough not to let trifles interfere, but on broad principles, prefer to let the next comer straighten matters out, if they require remedying.

The profession look at this differently, of course, and suffer under the disadvantage of being constantly called upon to reconcile discrepancies which are in their nature not reconcilable. But as long as owners are indifferent, I fear the profession will have to submit.

A great deal can be said upon the subject of abuses, but if a committee is to be appointed, it appears unnecessary just now to forestall their labors by discussion. I would suggest, however, that as we are fortunate enough to number among our members one or two of the legal profession, who generally take a practical view of such questions, that the Chair do not overlook them in naming a committee.

Mr. Wagoner—Before a committee of that kind is appointed it would be advisable, I think, to see what the law is on the subject.

Mr. Molera—I think, Mr. Wagoner, one of the functions of the committee, and probably one of the most important, would be to find out what is the law.

Mr. Wagoner—To find out the law, and to revise it.

Mr. Molera—And then report to this society the state of affairs. We can then have a discussion, and all of us suggest what remedies may be found, and then instruct the committee to present what amendments are necessary to the legislature.

Mr. Wagoner—There ought to be another matter in connection with that, and that is as to a method of establishing a finality to a survey. As I understand the law, the corner of any

object is the one that the existing County Surveyor makes; he may change the corners set by his predecessor.

Mr. Molera—Of course the corners by law are the corners of the public survey.

Mr. Wagoner—I speak of subdivision surveys. For instance, I call upon the County Svrveyor of this city to set me the corners of a lot, and another County Surveyor is elected and he resurveys it, and says the former survey is erroneous, and he makes it different; there is no redress.

Mr. Molera—O yes, certainly. The confirmation by the Deputy Surveyor or Deputy Engineer is simply *prima facie* evidence that it is correct. But of course you have to go to a court of law for any errors that have been made. Of course there are certain primary points in a city, which are recorded in the City Engineer's office, which all the other points depend upon. For instance, the corners of the blocks are established by the first survey, and those now are the established corners. Whether there is an error or not in them would make no difference in a matter of this kind.

Mr. Wagoner—I don't think you apprehend clearly what I said. We will grant the four corners are established; but we call upon the surveyor to make a subdivision and set us off a certain number of front feet, and he makes an error in that; well, I build on it; the next man has a survey made next to mine to test it, and he discovers my surveyor is wrong, and he can make me move my building or pay damages. That appears to be the law now.

Mr. Molera—There is the statute of limitations that would come in, which would be in your favor; for instance if you had been there in peaceable undisputed possession of that land for a certain length of time.

Mr. Wagoner—For five years; but the error may come up in less time than that.

Mr. Molera—Whether the last surveyor or the first surveyor made the mistake, the court would give you redress. But the

survey of the surveyor is simply *prima facie* evidence, and if there is no other reason the court will presume that is correct and right. But the point of finding the case and investigating it, if an error is found and the statute of limitations does not interfere with it, then of course the error is rectified. The City Surveyor is supposed to discharge his duties to the best of his ability, but sometimes he may be mistaken.

Mr. Raymond—No surveyor may be said to have any judicial function.

Mr. Wagoner—I think there ought to be one thing incorporated in such an act; that a surveyor should be empowered to take testimony about monuments. It is often the case where things of that sort come up that it is necessary to take testimony.

Mr. Molera—I think the question, as far as I understand it, is simply to regulate the filing of maps—the qualifications that the maps must have to be entitled to be filed as a public record. Is that your idea Mr. Raymond?

Mr. Raymond—Yes. I include in that the preparing of the maps and the filing. Of course the maps cannot be fully prepared until certain field work is done.

Mr. Wagoner—I think it was in 1884 I spoke to one of the State Senators, a prominent man, about something of the sort, and he said it could not be got through, no matter how much merit there was in it, because there was no money behind it.

TECHNICAL SOCIETY OF THE PACIFIC COAST.

INSTITUTED APRIL, 1884.

PROCEEDINGS.

(VOLUME VI.—No. 3.—1889-90.)

MINUTES OF MEETINGS.

No meeting in October.

REGULAR MEETING.

Friday, November 1st, 1889.

President M. Manson in the Chair.

Mr. Hubert Vischer delivered the paper prepared by himself and Mr. Luther Wagoner, entitled "Curved Dams." Their exhaustive treatment of the subject caused a lengthy discussion.

Adjourned.

N. S. KEITH, Sec'y.

REGULAR MEETING.

Friday, December 6th, 1889.

President M. Manson in the Chair.

Messrs. Behr, Vischer, Richards, Gutzkow and Isaacs were made the Nominating Committee to select candidates for the offices for the ensuing year. The Secretary was instructed to notify the gentlemen forming the Committee of the fact.

Mr. Raymond then read his paper, entitled: "A Graphical Method of Estimating Earthwork," which gave rise to an animated discussion, in which Messrs. Vischer, Wagoner and Manson took active part, as follows:

Mr. Vischer—It strikes me that the use of the prismoidal formula in connection with the calculations contemplated in

Professor Raymond's paper, is undesirable. As the planes of intersection are located with reference to an assumed datum, and spaced arbitrarily at some convenient equal distance apart, and are not located with reference to natural changes in the slope of the ground, there can be nothing gained in accuracy by using the prismoidal formula. As between either of the two sets of alternate sections, into which the planes may be grouped, neither can be selected as possessing greater accuracy than the other set; so that it is not logical to assign either four times the weight, or twice the weight, to one set that is assigned to the other set. The end area method is here a more correct one than the prismoidal formula, and as it simplifies the calculation considerably, I suggest its use. The formula on page 69 would then become—whether for an even or uneven number of sections—

$$V = \frac{h}{27}\left(\frac{A_1 + A_n}{2} + A_2 + A_3 + \ldots + A_{(n-1)}\right) \text{ cubic yards.}$$

Mr. Raymond—The solids computed are not all prismoids, and it is so stated in the paper. The end area method is perfectly suitable, and of course gives less work.

Mr. Vischer—The case which is illustrated by Figure 2 is one which often occurs in connection with the improvement of grounds, where, as the paper remarks, the only object is to smooth off the surface in a fitting manner. For this particular purpose I think Professor Raymond's figure a very instructive one, and a much more perspicuous method, both for arriving at results rapidly, and representing the differences between different possible schemes of grading, than is the ordinary method of representation on separate cross-section sheets. Great accuracy is never requisite in work of this kind, especially as the engineer generally has no connection with the work after establishing the grades and estimating the amount of work to be done. When the surface looks about right, the job is apt to be considered finished, and an extra fee for engineering service is usually avoided. The use of the planimeter may sometimes be a convenience; generally, however, I should feel inclined to select some less laborious method of area determination, especially where the areas happen to be elongated figures of no consider-

able height, such as Figure 2 shows. For such figures the planimeter gives results which are usually less accurate than intelligent guesses would be. The same planimeter, which for figures of considerable size and more or less square dimensions, might show an error of, say, one-half of one per cent. or less, would not even give a fair approximation, if used on some of the areas shown in Figure 2.

Professor Raymond—I had expected that that point would be raised against it. The figure was drawn to represent an extreme case, and to show how the other method would not fit very well.

Mr. Vischer—I had no intention of being hypercritical. I only wished to suggest the expediency of short methods, where approximate results are all that is required. I think your method a very useful one, and liable to be especially serviceable where contour sheets are already at hand and do not have to be specially prepared. It would be useful, too, in working up estimates for grading from plats, such as are usually furnished from the office of the City Surveyor. The plan is blocked off into squares and the elevations written in at the corner of each square, from which contours can usually be sketched in free hand.

Mr. Raymond—Much easier than by adjusting profiles crossing one another.

Mr. Molera—This method is used by French military engineers. I forget the English name for it, but the French name is *plans coteé;* Spanish, *planos acotados.* The curves are given and the elevations, and it is used for earthworks in fortifications, and so on. Instead of giving it in profiles, as is done in railroad work, a plan of the place is made, and the contour curves are placed on the plan. Where the ground is very abrupt more sections are made to the foot, or *vice versa* when less abrupt. Of course, all the fortifications are in regular planes. Then, from the drawings, the excavations and the filling-in is calculated by the prismoidal formula, which is a similar method to Mr. Raymond's. I suppose it is

used by the English and the American engineers, but I don't know what they call it.

Mr. Vischer—As regards the use of Professor Raymond's treatment, as applied to railway work, I would remark that contour maps are usually not much used on the Pacific Coast in railroad work; or, if used at all, the contours are generally only used to show the nature of the ground roughly, and are not close enough to furnish good data for the determination of quantities.

Professor Raymond—I had imagined that to be the case, and qualified my belief in the applicability for this special use accordingly.

Mr. Manson—While on the subject of fills, have you compared the various formulas as to their accuracy in cases of raising embankments—where there is no cut, but all fill, as in the case of building levees—with varying heighth, width of base and crown? Say a levee five miles in length and of various dimensions every 100 feet; one method is to average all the bases, average all the heights and average all the widths. Those composite dimensions make an average section, which multiplied by the length give the volume of earthwork in the levee.

Mr. Vischer—What was given; the side heights and center heights, or the center heights only?

Mr. Manson—The center heights.

Mr. Vischer—I think the method is given in Vose.

Mr. Manson—Given in several works, probably. Has any member compared that with formula of end areas, or any other method?

Mr. Vischer—I saw it applied by a railroad contractor once. The road was never built, but I remember that the quantities which he figured out did not check well with the correct quantities.

Mr. Wagoner—Replying to Mr. Manson's question, it may be granted that no errors would be made if, for such an embank-

ment described, a level average cross-section be assumed. Thus, if the top width (base) and side slopes are constant, the volume will be a function of the mean square of the depth. When it is required to estimate upon several types of embankment, the most rapid exact method is to find the mean depth and the mean square of the depth; these multiplied by the proper co-efficients will give the volume. For dams, and work where considerable difference of height occurs, it is most convenient to plat the squares of each vertical ordinate on the same sheet and find the area by the planimeter. When changes of volume are to be considered, arising from a parallel change in grade, it is only necessary to consider the surface layer times the change in grade, a function of the height. Hence, the change in volume would be $dV = L\,(sH + B)\,dH$. The above can also be applied to the adjustment of a grade line, so as to make the volume of the cuts and fills a minimum, as by introducing the proper constants the line can be adjusted to make the cost a minimum.

A Member (to Mr. Raymond)—Your reservation, on page 73, then only applies to the usefulness of the method as applied to railroad work? When I read the paper hastily I was in doubt.

Professor Raymond—The reservation only applied to this special case.

Mr. Vischer—Where the ground is very broken and irregular, I think Mr. Raymond's method would be as handy as any that I know of for railroad or canal work. On such ground, measurements have to be taken at points close to one another, and the data for fair contours is readily at hand. Undoubtedly, it would often pay to draw in contours for a piece of broken ground, and then to work from the plan, instead of from the cross-section notes. I wish to remark that there appears to be a typographical error on page 71, line 24: a capital letter G is used; it should be a small *g*, to correspond with the diagram.

Professor Raymond—Such an error has been made. I had not noticed it before. I did not have the cuts when I read the proof.

Adjourned. N. S. Keith, Sec'y.

REGULAR MEETING.

Friday, January 3d, 1890.

Vice-President Molera in the Chair.

The following propositions for membership were made:

Arthur F. Bell, by N. S. Keith.

H T. Bestor, as member, by G. W. Percy, E. J. Molera and H. C. Behr.

H. P. Dimond, as associate, by L. Wagoner, H. Vischer and G. W. Percy.

Burr Bassell, as member, by P. J. Flynn, F. K. Zook and Geo. G. Knox.

Jas. W. Reid, as member, by G. W. Percy, Luther Wagoner and H. Vischer.

Geo. F. Schild, as member, by Otto von Geldern, H. Vischer and J. Richards.

Professor G. W. Raymond then read a paper entitled "What Constitutes a Map?" After discussing the subject for some time, Professor Raymond moved that a committee of five be appointed to consider the subject of preparing an act for the Legislature, regulating the legal filing of maps. Passed.

The Chair then appointed on that committee Messrs. Hall (Chairman), Raymond, Wagoner, Harrison Smith and Harold Wheeler.

The Committee on Nominations submitted a written report which was adopted and was ordered printed for distribution.

Messrs. Behr and Raymond were appointed judges of election to serve at the annual meeting.

Adjourned.

N. S. KEITH, Sec'y.

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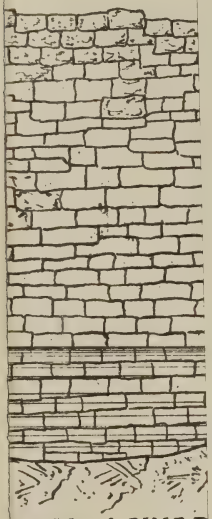
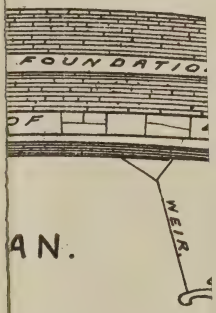
, ENGR.



FROM LOWER



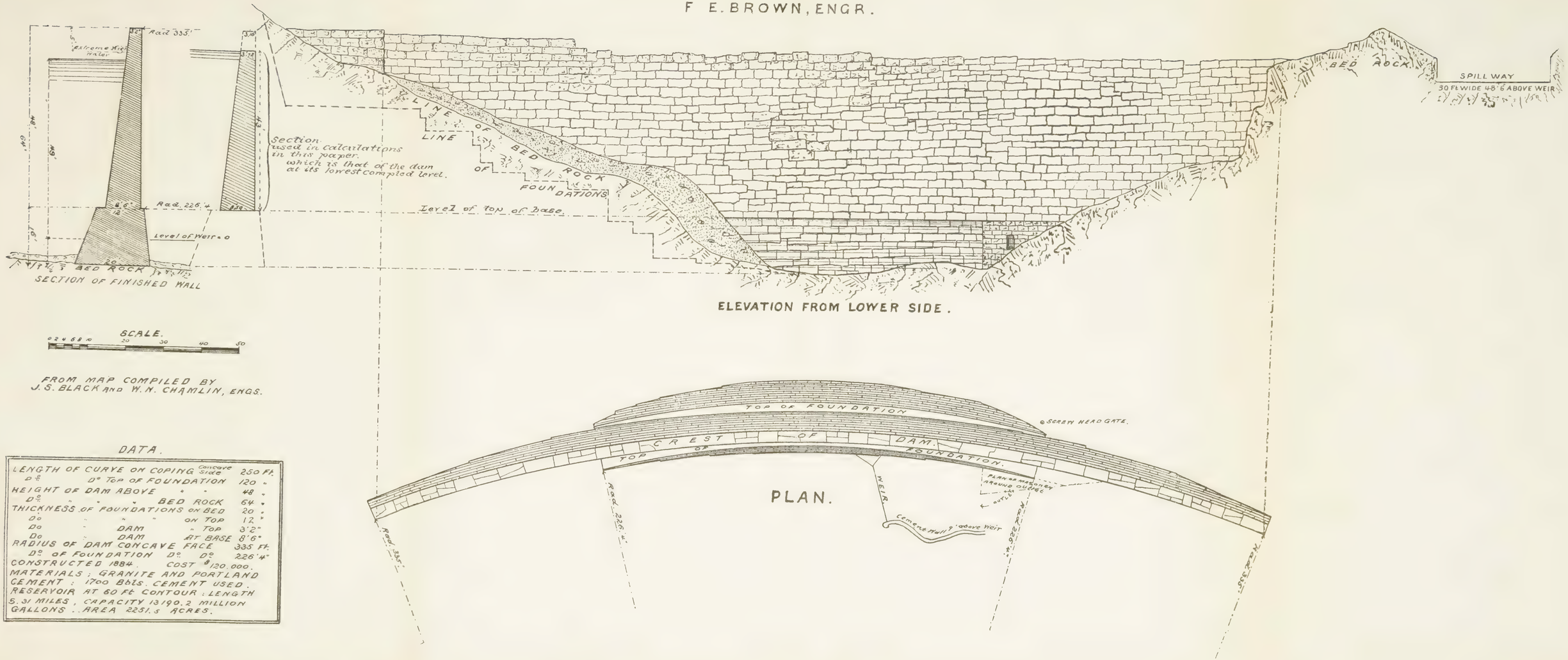
AN.

BEAR VALLEY DAM.

SHEET 1.

SAN BERNARDINO COUNTY CALIFORNIA.

F. E. BROWN, ENGR.

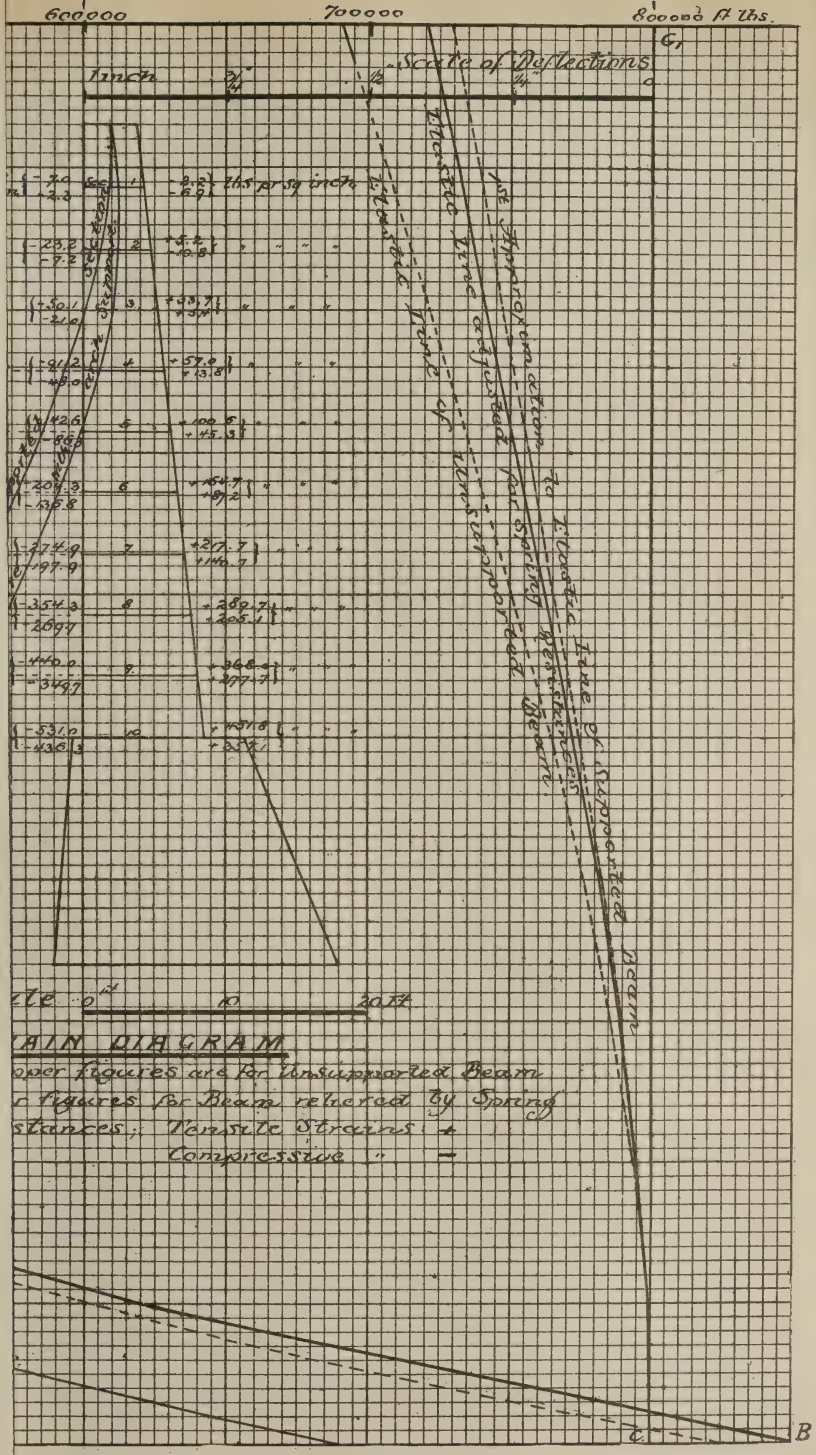


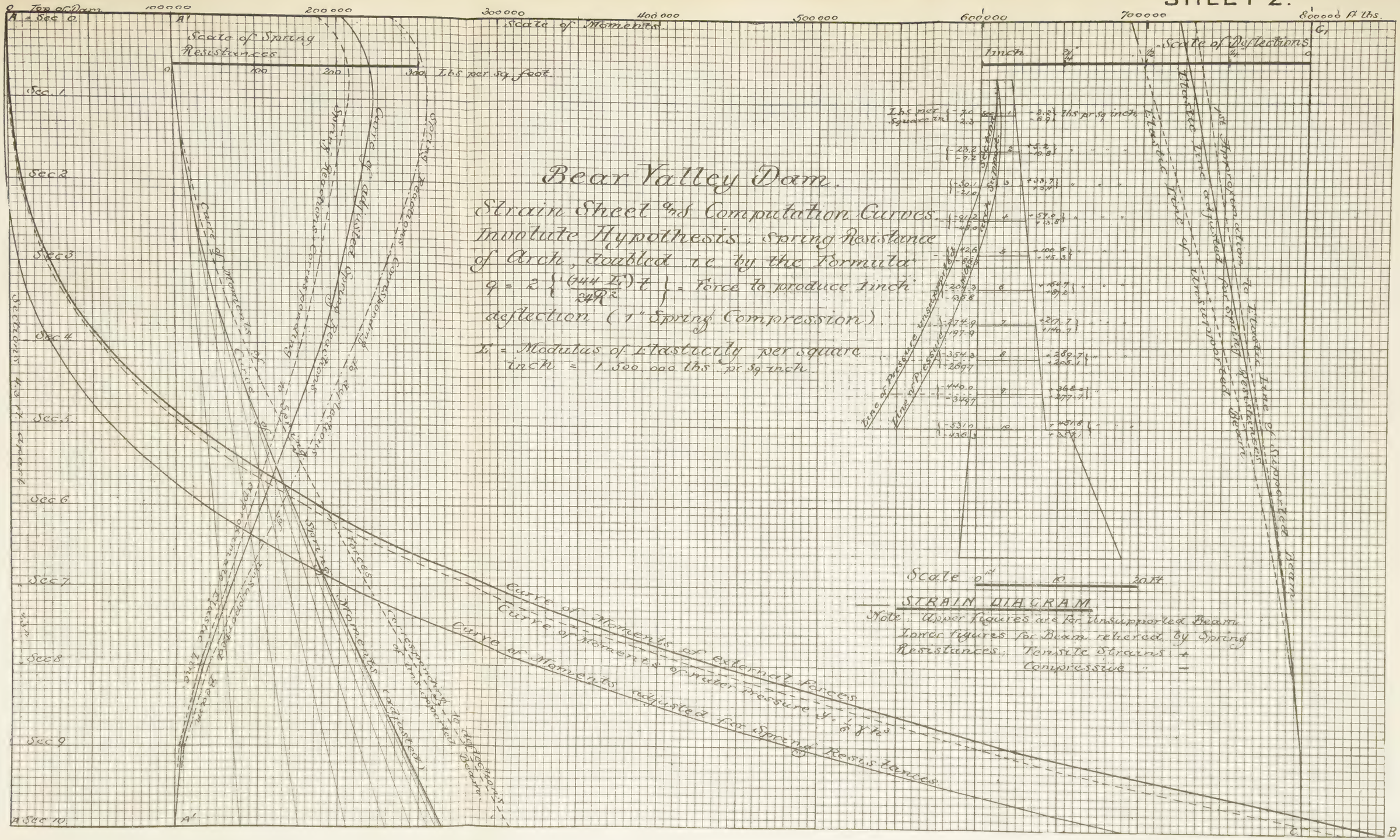
DATA.

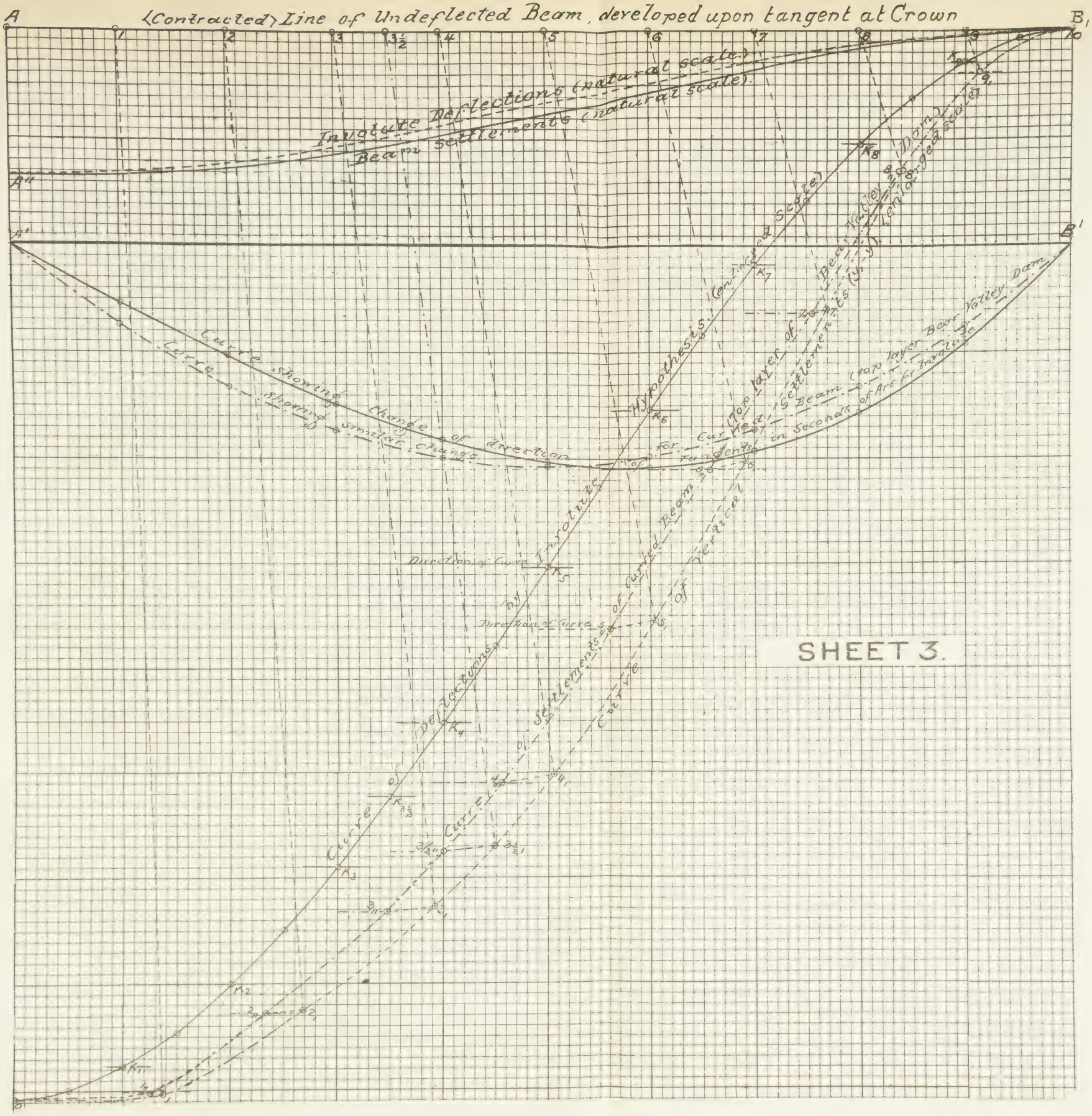
LENGTH OF CURVE ON COPING (Concave Side)		250 Ft.
D° D° TOP OF FOUNDATION		120 "
HEIGHT OF DAM ABOVE	" "	48 "
D° " " " BED ROCK		64 "
THICKNESS OF FOUNDATIONS ON BED		20 "
D° " " " ON TOP		12 "
D° " DAM " TOP		3'2"
D° " DAM AT BASE		8'6"
RADIUS OF DAM CONCAVE FACE		335 Ft.
D° OF FOUNDATION D° D°		226'4"

CONSTRUCTED 1884. COST $120,000.
MATERIALS; GRANITE AND PORTLAND CEMENT: 1700 Bbls. CEMENT USED.
RESERVOIR AT 60 Ft. CONTOUR: LENGTH 5.31 MILES, CAPACITY 13190.2 MILLION GALLONS. AREA 2251.5 ACRES.

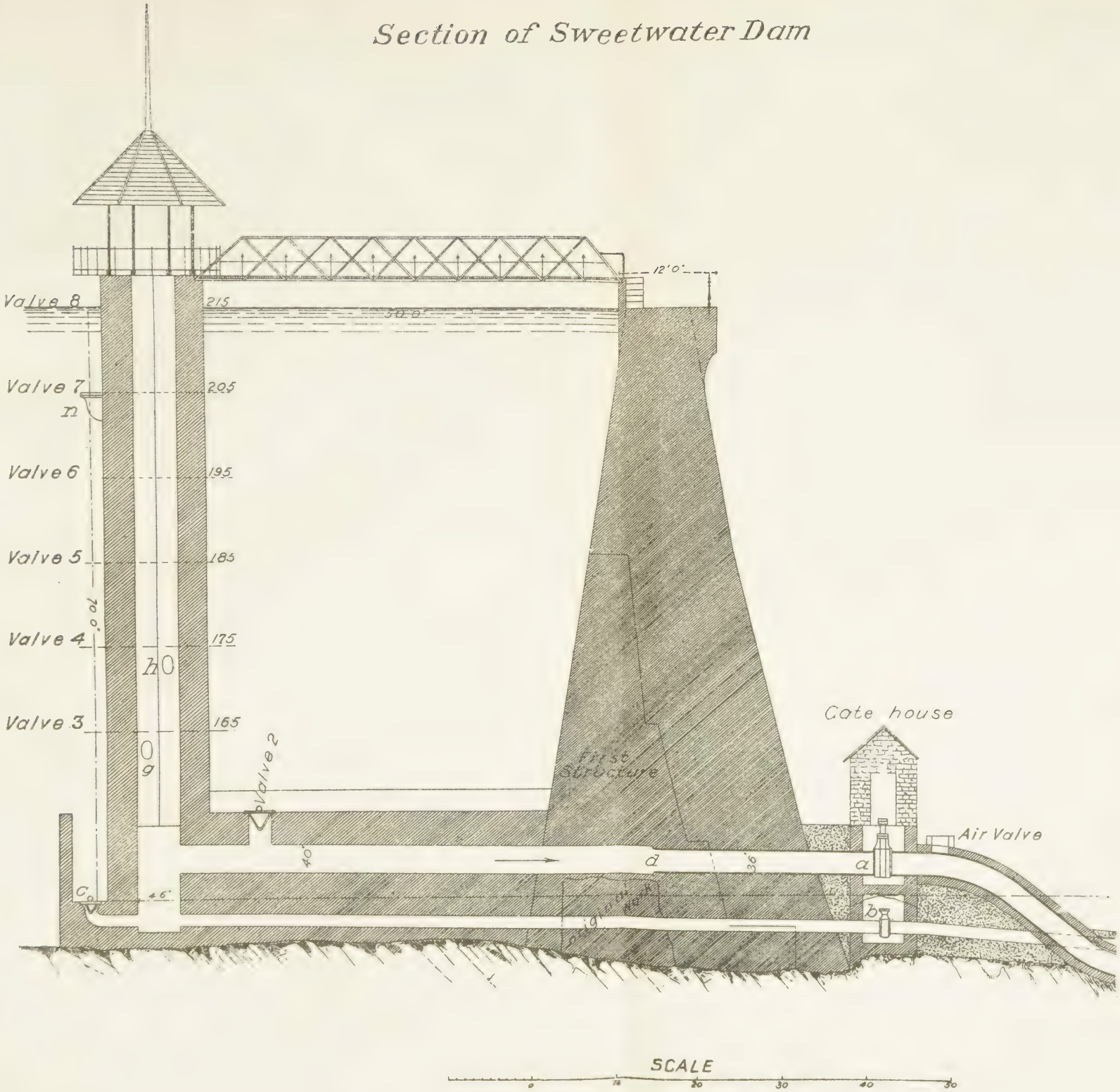
SHEET 2.


600000
700000
800000 ft lbs.
Scale of Deflections
1 inch
lbs pr sq inch
Elastic Line of Unsupported Beam
Elastic Line adjusted for Spring Resistances
1st Approximation to Elastic Line of Supported Beam
0 ft
10
20 ft
AIN DIAGRAM
oper figures are for Unsupported Beam
r figures for Beam relieved by Spring
stances; Tensile Strains +
Compressive " −
B


Bear Valley Dam.
Strain Sheet and Computation Curves.
Involute Hypothesis: Spring Resistance of Arch, doubled i.e. by the Formula
q = 2 {(144 E / 24R²) t} = Force to produce 1 inch deflection (1" Spring Compression).
E = Modulus of Elasticity per square inch = 1,500,000 lbs. pr sq inch.
Scale of Spring Resistances
Lbs per sq foot
Scale of Moments
Scale of Deflections
Sections 4.3 ft. apart
Curve of Moments of external forces
Curve of Moments of water pressure
Curve of Moments adjusted for Spring Resistances
Spring Reactions Corresponding to deflections
Curve of adjusted Spring Reactions
Curve of Moments adjusted for Spring Resistances
Elastic Line of Supported Beam
Elastic Line of Unsupported Beam
1st Approximation to Elastic Line of Supported Beam
Elastic Line adjusted for Spring Resistances
Line of Pressure Unsupported
Line of Pressure Supported
Scale 0 10 20 Ft.
STRAIN DIAGRAM
Note: Upper figures are for Unsupported Beam.
Lower figures for Beam relieved by Spring Resistances; Tensile Strains +
Compressive " −


A
B,
(Contracted) Line of Undeflected Beam, developed upon tangent at Crown
Inflexure Deflections (natural scale)
Beam settlements (natural scale)
A''
A'
B'
Curve showing similar change of direction
Curve showing change of direction
Hypothesis
Curve of Deflections
Curve of Settlements
Curve of Deflections
Curve of Settlements
Curve of Deflections
Curve of Settlements

Section of Sweetwater Dam



TECHNICAL SOCIETY OF THE PACIFIC COAST.

INSTITUTED APRIL, 1884.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the statements and opinions advanced in any of its publications.

(VOLUME VII.—FEBRUARY, 1890.)

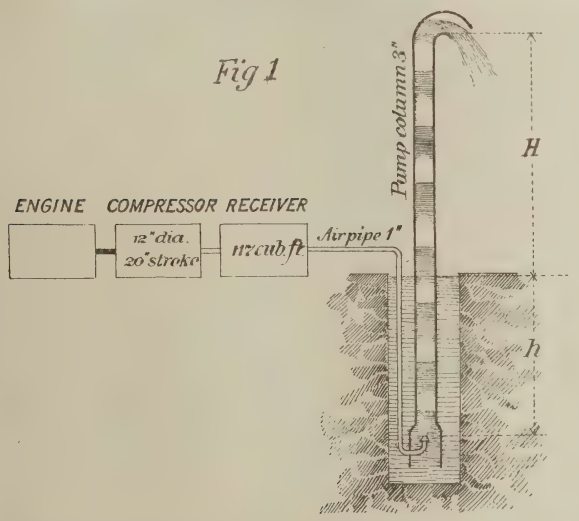
DR. POHLÉ'S AIR-LIFT PUMP.

BY ROSS E. BROWNE AND H. C. BEHR, Members Tech. Soc.

[Read February 14, 1890.]

During the month of August last, the writers, jointly with Mr. P. M. Randall, conducted a series of tests with Dr. J. G. Pohlé's air-lift pumping apparatus.

The following sketch will show the simplicity of the pump:

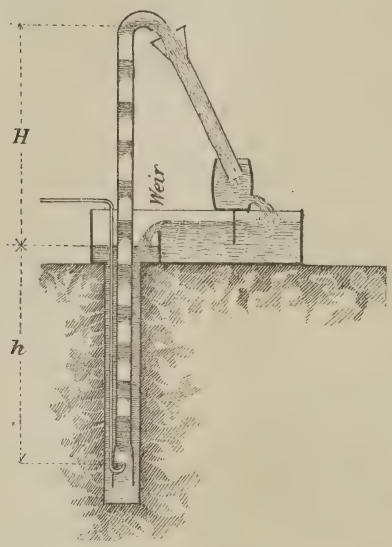


A good efficiency being found, and the apparatus having, for

many purposes, very apparent advantages over the forms of pump in common use, it is thought that a record of the tests may be of interest.

The pump column is an open pipe partly submerged in the water to be pumped. A small pipe leading from an air receiver to the foot of and a short distance into the pump column, delivers compressed air, which forms in piston-like layers, and rising rapidly in the column, does the work of pumping. The water is discharged in alternate layers with the air.

Fig. 2



The apparatus tested, was erected without due regard to best dimensions, and we deem it proper to state that the efficiencies found could have been increreased by a few simple alterations. Pipes of different diameters were not provided, and we were able to change only the length of the pump column, the amounts of submersion and lift, and the pressure in the receiver, hence the quantity of air supplied.

The diameter of the pump column was 3 inches, of the air pipe 0.9 inch, and of the air discharge nozzle $\frac{5}{8}$ inch. The air

pipe had 4 sharp bends and a length of 35 feet + the extent of the submersion.

The water was pumped from a closed pipe well (55 feet deep and 10 inches in diameter), and was discharged into a tank and delivered—over a quadrantal weir—back to the well.

A long mercurial column was connected with the receiver for the purpose of obtaining accurate measurement of pressure.

The quantity of air delivered to the pump was obtained by two methods, as follows:

1*st Method.*—The cubic contents of the receiver was measured. The escape cocks from the receiver were closed and the compressor was started. Beginning with atmospheric pressure, the increase of pressure was noted for each 30 strokes of the compressor-piston, until a pressure was reached beyond that required in the pump tests.

The contents of the receiver was 117 cubic feet.

The following are the results of two separate tests:

The compressor made uniformly one stroke per second. The atmospheric pressure was 2.51 feet of mercury. The air was unusually dry.

TABLE I.

No. of Strokes of Compressor-Piston.	Temperatures.				Pressures in Receiver above Atmospheric. Feet of Mercury.	
	Receiver.		Atmosphere.			
	Test No. 1.	Test No. 2.	Test No. 1.	Test No. 2.	Test No. 1.	Test No. 2.
0	78° F	80° F.	75° F.	77° F.	0	0.01
30	.....	.....	.....	.....	(0.76) ?	0.94
60	.....	.....	.....	.....	1.72	1.77
90	.....	.....	.....	.....	2.48	2.56
120	.....	.....	.....	.....	3.24	3.31
150	.....	.....	.....	.....	3.95	4.08
180	.....	.....	.....	.....	4.67	4.81
210	.....	.....	.....	.....	5.34	5.54
240	.....	.....	.....	.....	6.00	6.29
270	86°	88°	75°	77°	6.66	7.00

These data formed the basis for calculating the number of pounds of air delivered, per piston-stroke of the compressor, to the receiver at any required pressure. An average of the results of the two tests was adopted. The following table gives the values obtained:

TABLE II.

Pressure in Receiver above atmospheric. Lbs. per square inch.	0	5	10	15	20	25	30	35	40
Lbs. of air delivered per stroke of Compressor..	.104	.098	.093	.088	.083	.081	.079	.077	.076

2d Method.—A small auxiliary chamber, B, was attached to the receiver. See Fig. 3. Compressed air entering this chamber escaped into the atmosphere through a carefully-measured circular orifice in thin plate. After a pump test had been completed, the compressor was kept running, cock C was closed, and cock A opened and adjusted until the conditions in the pump test, regarding number of strokes of compressor per minute and the pressure in the receiver, were repeated and maintained.

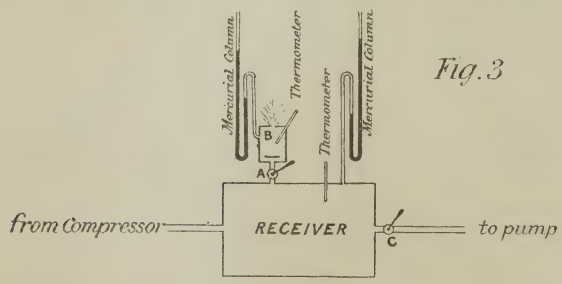


Fig. 3

The pressures and temperatures of the compressed air in chamber B and of the atmosphere, furnished the data upon which to base a calculation of the quantity of air escaping through the circular orifice. This quantity was evidently the same as that supplied in the pump test. Such tests were made from time to time, and served to check the values taken from Table II. A few of these are given below. Diameter of orifice was 0.391 inch. Atmospheric pressure 14.7 lbs. per square inch. Weisbach's and Zeuner's coefficients of efflux were used.

TABLE III.

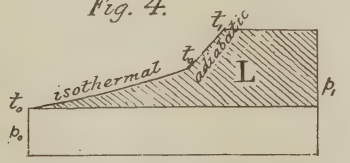
No. of Pump Test.	No. of strokes of Compressor per minute.	Pressures above atm., lbs. per sq. in.		Temperatures F.			Lbs. of air delivered per second.	
		Receiver.	Chamber B.	Receiver.	Chamber B.	Atmosphere.	Table II.	Orifice Test.
1	60	31.1	20.2	77	77	68	.078	.075
5	60	30.6	20.3	74	73	73	.078	.075
10	60	24.1	21.7	78	75	74	.081	.077

The engine used to drive the compressor was built for ten times the power actually applied to the compressor, hence a test of the efficiency of the entire plant was not made.

Table IV gives the results of the pump tests. The "efficiency of the pump" is based upon the least work (L) theoretically required to compress the air and deliver it to the receiver. See Fig. 4.

Atmospheric conditions.....p_0, t_0.
Receiver " .....p_1, t_1.

Fig. 4.



The values given in the table take no cognizance of the losses of power in the engine and compressor.

If we assume the efficiency of a suitable compressor to be 70 per cent., the efficiency of the pump and compressor together would be 70 per cent. of that given in the table for the pump alone.

TABLE IV.

No. of Test	No. of Strokes of Compressor per minute	Pressure in Receiver above atmospheric lbs. per square in.	Temperatures Fahr. Receiver	Temperatures Fahr. Atmosphere	Temperatures Fahr. Water	Water lift "H" in feet	Submersion "h" in feet	Pressure corresponding to "h" lbs. per sq. in.	Weight of air supplied lbs. per sec.	Water pumped cubic feet per sec.	Work of isotherm. Compression L, ft. lbs. per sec.	Work of water lift, W, ft. lbs. per sec.	Ratio $\frac{H}{h}$	Efficiency of pump $\frac{W}{L}$ in %
1	60	31.1	77	68	68	75.2	53.0	23 0	.078	.1755	2408	824	1.4	34
2	60	30.8	77	72	68	75 4	52.8	22.9	.078	.1799	2454	846	"	34
3	45	27.6	78	71	68	75.3	52.9	22.9	.059	.1488	1716	700	"	41
4	31	25.4	77	74	68	75.3	52.9	22.9	.041	.0757	1156	356	"	31
5	60	30.6	75	72	67	35.1	53.2	23.1	.078	.3136	2459	687	0.6	28
6	46	26.8	78	74	67	35.2	53.1	23.0	.061	.3014	1770	662	"	37
7	30	24.9	78	76	67	35.0	53.3	23 1	.041	.2425	1150	530	"	46
8	22	24.0	78	72	67	35.0	53.3	23.1	.030	.1941	802	424	"	53
9	60	23.8	78	72	70	54.7	33.6	14.6	.081	.1538	2151	525	1.6	24
10	34	17.4	77	72	69	54.7	33.6	14.6	.049	.0824	1056	281	"	27
11	23	16.1	76	73	69	54.5	33.8	14.6	.033	.0576	681	196	"	29
12	60	18.8	76	71	69	69.9	18.4	10.0	.084	.0338	1904	147	3.8	8
13	33	11.9	76	75	69	69.6	18.7	10.0	.050	.0067	837	29	"	3
14	60	20.6	80	77	69	62.1	26.2	11 4	.083	.0931	2041	361	2.4	18
15	38	15.2	80	74	70	62.4	25.9	11.2	.056	.0663	1090	258	"	24
16	19	12.3	79	75	71	62.4	25 9	11.2	.029	.0185	489	72	"	15
17	60	18.9	79	74	67	31.5	20.1	8.7	.084	.1488	1922	292	1.6	15
18	34	12.3	78	72	68	31.5	20.1	8.7	.052	.1126	860	221	"	26
19	20	10.0	76	70	68	31.3	20.3	8.8	.031	.0633	432	124	"	29
20	60	20.3	69	68	67	26.3	25.3	11.0	.083	.2296	2013	377	1.0	19
21	41	15 8	70	66	67	26.3	25.3	11.0	.059	.2050	1178	336	"	29
22	22	12 5	70	67	67	26.3	25.3	11.0	.033	.1420	558	233	"	42
23	60	21.9	72	67	69	20.3	31.3	13.6	082	.2954	2050	374	0.7	18
24	27	15.1	72	67	69	20.3	31 3	13.6	.040	.2398	769	304	"	39
25	22	14.4	72	67	69	20.3	31.3	13.6	.032	.2086	594	264	"	44
26	60	23.1	74	67	69	15 3	36.3	15.7	.082	.3540	2105	338	0.4	16
27	30	17.4	73	68	69	15.3	36.3	15.7	.043	3182	918	304	"	33
28	19	16.2	73	69	69	15.3	36.3	15.7	.028	.2558	572	244	"	43
29	60	17.1	74	69	69	36.0	15.6	6.8	.086	.0693	1818	156	2.3	9
30	34	10.1	73	70	70	36.0	15.6	6.8	.052	.0424	749	95	"	13
31	18	7 4	73	70	70	36.0	15.6	6 8	.029	.0093	323	21	"	7
32	60	15.8	76	72	70	41.0	10.6	4.6	.087	.0146	1757	37	3 9	2
33	22	7.1	74	72	70	41.0	10.6	4.6	.035	0	382	0	"	0

An inspection of the above table shows:

1st—That, for a given submersion "*h*" and lift "H", the best efficiency was obtained when the pressure in the receiver did not greatly exceed the pressure due to the submersion. *

2d—That the smaller the ratio $\frac{H}{h}$, the better was the efficiency.

We may say in a general way that under the better adapted pressures in the receiver, the pump, as erected, showed the following efficiencies:

For $\frac{H}{h}$ =	0.5	50 %.
" "	1.0	40
" "	1.5	30
" "	2.0	25

It is apparent that the air pipe should not have been reduced at the discharge end, as such reduction necessitated a greater pressure in the receiver for the delivery of the air to the pump.

Unfortunately, the data is wanting for a reliable estimate of the loss due to the frictional resistance in the small air pipe. A rough estimate shows that such loss must have been large. The substitution of a $1\frac{1}{2}$ inch air pipe in place of the 1 inch would have appreciably augmented the efficiencies given in the table. In justice to the pump, a considerable allowance should be made for this easily avoidable loss.

The last test, No. 33, shows a limit of lift for a given submersion, beyond which a large excess of pressure is required to pump even an insignificant quantity of water.

For good efficiency, it becomes necessary that the lift should not be very great as compared with the submersion.

Where a shallow sump only is available to pump from, and a considerable lift is to be made, Dr. Pohle introduces an auxiliary pipe to receive the water, after being pumped to a small height, and act as pump well for a higher lift. See Fig. 5.

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*Note.—This was only true when the ratio $\frac{H}{h}$ was kept within reasonable limits—*i. e.* where H was not much greater than *h*.

We have not attempted an analytic treatment of the action of this pump. Such treatment would have little value without coefficients, derived from a more comprehensive set of tests.

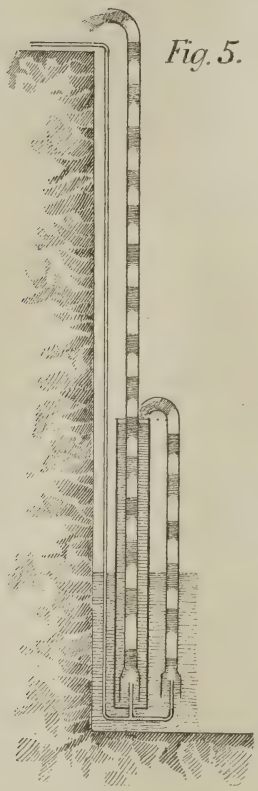

Fig. 5.

The simplicity of this pump commends it for many uses.

Among the numerous applications which Dr. Pohlé proposes for this air-lift may be mentioned: the drainage of mines; the supply of water from deep wells; the lifting of liquids which damage the working parts of the pumps ordinarily used; the increase of the lift and capacity of other pumps by introducing an air jet into the pump column.

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TRANSACTIONS.

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NOTES ON THE DRY DOCK AND COFFER-DAM AT THE NAVY YARD, MARE ISLAND, CALIFORNIA.

BY OTTO V. GELDERN, C. E., Mem. T. S. P. C.

[Read March 7, 1890.]

At the Navy Yard, Mare Island, an engineering work of some magnitude was begun in 1872, which, although not yet finished, has been open for about three years and put to the use for which it was designed. I refer to the stone dry dock.

The long history of its construction, running through a period of fifteen or sixteen years, would be an interesting one to the profession, but the time placed at my disposal did not admit of extensive treatment, but confined me to general statements only, which are based upon data collected as far back as 1876.

When the work was contemplated, the following general dimensions were adopted by the Navy Department, in accordance with which a plan was made by Mr. Calvin Brown, Civil Engineer, then the chief constructing engineer of the navy yard.

DIMENSIONS OF STONE DRY DOCK ORDERED 1872.

Depth of water on entrance arch	27′ 6″
Depth of arch below coping	32′ 6″
Width of entrance	78′ 0″
Depth of chamber floor below coping	36′ 6″
Width of chamber floor	30′ 0″
Width of chamber at coping	104′ 0″
Length of chamber to center of head on floor	360′ 0″
Length of chamber to first altar on floor	378′ 0″
Length of chamber to head at coping	412′ 0″

The structure was to be mainly of concrete, laid upon piled foundation if necessary, with exterior top courses of large granite blocks, to constitute the floor and form a system of steps and altars leading from the bottom to the coping at the top. The whole was to have the shape of an inverted arch, and this principle was carried out in the design, in which every granite block was carefully drawn to the lines of the arch. (See appended cross-section of the dock.) The dimensions which I have just given were subsequently changed. Forty feet were added to the length of the chamber, making it 400 feet from the caisson-arch to the center of the circular head; and still later on, when the work was in progress, the dock was widened, which destroyed the shape of the arch. I shall refer to this point again further on.

The drain-culverts were designed to run along the sides of the dock, leading to a well and pump-house at the head of it, all of which, in addition to the emptying-culvert from the well to the bay, constituted the system for bailing out the chamber; while the filling culverts, laid through the tail end, served, by means of adjustable wicket-gates, to open a direct communication between the bay and the chamber of the dock.

The entrance-arch held the device for keeping the water from the emptied chamber; a floating caisson was to be adopted with appliances for lowering and raising it in place.

Mr. Brown was sent to Europe, to examine similar structures in England and France, and upon his return he reported to the Navy Department pointing out the great utility of concrete in all works of that kind, and the extensive use made in France of

beton and artificial stone structures. But in his concise report he rather recommended the system of a floating dock, to be used in connection with large dock-basins and a number of hauling-ways, (in which the dock is merely the vehicle to transport the vessel to the ways, where it may be hauled ashore and moved inland as far as desired)—in preference to the system in vogue in England, where a number of permanent docks are accessible from a wet or mooring basin. This preference was expressed not for any single structure, for he advocated the building of one permanent dock for every naval station, but for a comprehensive design to be laid down for requirements of the future. His reason was the very great cost of the latter system when compared with that of marine-ways, any number of which may be accommodated by one floating design.

After studying the location for a site and taking numerous borings over the selected ground, work was begun August 13th, 1872, when the first gang of men started the excavation of the pit. This work was subsequently let out to a contractor, after the government had removed 18,900 cubic yards in about ten months. The contract called for excavating a pit something like 40 feet deep, containing about 90,000 cubic yards, which were to be removed in 120 days, and the price contracted for was 74 cents currency per cubic yard.

The contractor began his operations in July, 1873, and continued until September 5th, 1874, when his contract was annulled by the government. He had removed about three-fourths of the material from the site when he was stopped.

The failure was due mainly to the fact that the contractor did not carefully consider all conditions likely to arise in a work of that character, before undertaking it at so low a figure. The difficulties accumulated the deeper he got into the earth. His method of removing the material from deep cuts was by cars run on a track to a double vertical hoist, moved by a steam engine from the bank above. When working well he would remove from 300 to 350 cubic yards of earth per day, employing forty-three men to do the immediate excavation in the pit, and

some twenty-five more to dispose of the spoil on the bank above. This refers to work done when the pit had considerable depth. Blasting was made use of in the early part of his work, but this had to be discontinued in localities close to the coffer-dam.

After the collapse, the contractor had numerous grievances, which led to a claim for damages against the United States, the tedious but thorough investigations of which lasted through a period of over ten years. They form an interesting study in themselves, but we shall not dwell upon them here. The final settlement of this complicated case, I believe, has not been brought about as yet. It remained for the department to complete the earthwork, which was gradually accomplished by taking out small quantities from year to year.

The progress made in this structure after the year 1874 or '75 was very slow, as the appropriations made by Congress were never commensurate with the magnitude of the work. Political and party interests governed almost every detail, and all the disadvantages under which the dock was built and finally completed, are principally due to that cause.

The location chosen was a very desirable one. At the tidal area of the site hard bottom was found 35 feet below the highest tide, upon which rested a layer of soft mud from 15 to 20 feet deep. The excavation extended to a depth of about 40 feet below the same plane, the soil being a stiff bluish and yellow marly clay after reaching depths of 25 feet or more. I do not believe that water was ever encountered to any great degree; at all events no serious difficulty was experienced in providing a foundation for the floor of the dock. As far as I know, the concrete bed rests directly upon the hard soil under it for the full length and breadth of the structure.

During the progress of the excavation the coffer-dam was begun. This structure was designed by Mr. Brown, after determining its probable location, and consisted of three rows of 15x15-inch sheet-piling, the rows 16 feet apart, closely driven, connected by 12x12-inch wale-pieces at distances of one foot and ten feet below the piling of the dam, which was cut off uniformly

at some reasonable height above the highest water. The piles were driven through a layer of mud into a hard argillaceous material, the mud overlying the hard bottom from 15 to 20 feet or more in places. I have added a table showing the lengths of the piles and the depths driven into the hard bottom.

The front face of the dam was made 240 feet long, with wings at each end, running at right-angles to the front shoreward for a distance of about 100 feet. Beyond that point there projected a double row of lighter piling at each wing, deflected slightly outward in alignment, extending to the firm ground about 100 feet further. The front of the dam ran parallel with the water front of the navy yard, the inner row being about 80 feet outside of the high water line. The three rows of the double structure, as well as the two rows of the single portion, were tied together by 2-inch iron rods,—through both the upper and the lower waling, at distances of 10 feet from rod to rod. To add to the greater stability of the front, four buttresses, consisting of 24 15x15-inch piles each, were driven at right-angles to its inner row; they were braced with heavy timbers laterally and tied to the three rows by a long cap running over the tops of the piles. (See the appended drawings of the dam.) Similar buttresses were added to the wings, but not until signs of weakness were manifested there, when three were added to the north wing and five to the south wing.

The first pile of the coffer-dam was driven on September 17th, 1872, when the south wing was begun, and for the period of about a year this work was carried on and pushed toward completion. By the end of March, 1873, the dam had so far advanced as to admit of the puddling between the rows of the piling, which was done by filling these compartments with the stiff material taken from the dock pit, and ramming it with tampers when the fill became high enough. An opening had been left at the northern end of the front for the purpose of allowing the soft mud, overlying the hard bottom to a depth of 15 or 20 feet, to escape as it was pushed forward toward that gap. The clay used for puddling was found to pack well and solidly, easily forcing away the softer material which it had to replace.

By the beginning of October, 1873, the dam had been closed and the tidal area within, some 20,000 square feet, no longer communicated with the waters of the bay. Adequate pumping facilities had been prepared, and the work of laying dry the lower end of the dock site was started. There must have been all of thirteen feet of water within the dam when the pumps began to work. The weak spot proved to be the junction of the north wing and front, at the place where the gap had been left to the last. On October 4th, the pumps had been worked all through the night until 5 o'clock on the morning of the 5th, when the dam gave away at that point. The outer row was pressed outward, the inner row inward, and the wale-pieces were bent like reeds under the strains. The water had then been pumped down to a depth of 2′ 6″ below the average low tide, which would correspond to about 8 feet pumped. The water again found its way through the dam before preparations could be made to repair the damage done. No effort was spared after that to strengthen and stiffen this corner. This was done by additional bracing, by running continuous timbers from wing to wing, locking in at the end of each buttress, and by large iron straps tying the front to the wing. After the break had been thoroughly repaired and the puddling renewed, the water was kept at the 2′ 6″ level by pumping a little from day to day, until the 21st of November, when the order was given to "pump out," and by December 1st nearly the whole surface was laid dry. I do not think that the dam ever gave any trouble after that. As it settled into its final position the front face was slightly distorted and the structure manifested a tendency to lean in, but it remained firm and gave no cause for alarm. The leaks which occurred amounted to so little, that a small pump operated occasionally from day to day kept the area free.

This dam stood perfectly well for twelve or thirteen years until it was removed, proving a success as a barrier against the waters of the bay. In its last years it may have given some anxiety through fear of decay, but since it was never exposed to any violent action of the sea, and not attacked by teredo or limnoria, from which this bay is free, there was really nothing to be feared that ordinary skill and diligence could not have anticipated, or that a practical engineer should not have been prepared for.

The amount of material used in its construction is as follows:

FOR THE NORTH WING—SHEET PILING.

46	pieces	4 x 12″	yellow	pine	timber,	20	feet	long
170	"	6 x 12″	"	"	"	22 to 30	"	"
189	"	15 x 15″	"	"	"	35 to 50	"	"

The latter driven from 6 to 14 feet into hard bottom.

FOR THE SOUTH WING—SHEET PILING.

85	pieces	4 x 12″	yellow	pine	timber,	24 to 36	feet	long
77	"	6 x 12″	"	"	"	35 to 40	"	"
30	"	8 x 16″	"	"	"	44	"	"
184	"	15 x 15″	"	"	"	40 to 60	"	"

The latter driven from 6 to 14 feet into hard bottom.

FOR THE FRONT—SHEET-PILING OF INNER ROW.

132 pieces 15 x 15″ yellow pine timber, 55 feet long, driven from 12 to 19 feet into hard bottom.

SHEET-PILING OF MIDDLE ROW.

155 pieces 15 x 15″ yellow pine timber, 57 to 60 feet long, driven from 17 to 22 feet into hard bottom.

SHEET-PILING OF OUTER ROW.

182 pieces 15 x 15″ yellow pine timber, 60 to 65 feet long, driven from 17 to 22 feet into hard bottom.

To all of which 20 wedge-piles and 80 guide and brace-piles must be added.

FOR BUTTRESSES—SHEET-PILING.

100 pieces 15 x 15″ yellow pine timber, from 55 to 58 feet long, driven from 18 to 20 feet into hard bottom.

192 12″ round piles, 45 feet long.

FOR WALING AND BRACING.

2280	lin. feet	6 x 12″	yellow	pine	timber
273	" "	8 x 12″	"	"	"
5752	" "	12 x 12″	"	"	"
360	" "	15 x 15″	"	"	"

FOR A ROW OF FENDER PILES, TO GUARD THE WATER FRONT OF THE DAM.

72 14″ round piles, 50 feet long.
250 lin. feet 12x12″ timber.

FOR A PASSENGER BRIDGE FROM WING TO WING.

98 12″ round piles, from 25 to 45 feet long.
540 lin. feet 12x12″ timbers for capping.
15 pieces 12x12″ timber, 30-foot lengths, for cross-stringers, and the required planking for the walk.

FOR LANDING-PIERS AND BOILER FOUNDATION.

60 12″ round piles, 50 to 70 feet long.
373 lin. feet 12x12″ yellow pine timber.
60 " " 16x16″ " " "
1140 " " 3x12″ planking.
10220 feet B. M. 4x12″ scantling, besides the planking for the wharf.

This includes the timber used to the time when the dam was considered completed in 1873. In subsequent years, that is ten years afterwards, when the excavation and masonry were carried on within the wings, considerable additional work in the way of shoring from the inside was done, which is not included in this estimate.

The iron work of the dam consisted of a number of heavy straps; and of the tie-rods between the rows, of which perhaps 200 were used, 2 inches in diameter, from 15 to 20 feet long, with bolts, nuts, screws, washers, &c. All the work on the dam was done by hired labor.

With the amount of material it will be a simple matter to make an estimate of the cost of this structure, as simple as it would be difficult to tell what it actually did cost.*

With the very best supervision and every intention on the part of the chief engineer to prosecute the work in a proper manner, innumerable obstacles were put in the way of a proper administration, the battle with which occupied a good portion of the time.

*The amount estimated for it was $93,000.00.

As an illustration, a case may be cited in which an Eastern firm succeeded in selling the Navy Department two so-called gunpowder pile-drivers* for use on the coffer-dam at Mare Island. Asside from the fact that the dam was nearing completion when one of them was received, set up and ready to be experimented with, they cost a great deal of money and never worked satisfactorily. I think the price of the smaller one (40 feet high) was $2,000.00, and of the larger one (50 feet high) $2,500.00, delivered at the railway station in sections. Besides that there was a charge of $3,000.00 for the right to use them, if I remember correctly. The device consisted of steel frames, set up in gins as in the ordinary pile-driver. These frames formed the guides for the gun and the plunger. The gun or mortar resembled a pile-driver hammer in shape, weighed about 3,000 pounds, and was made to fit the top of an adjusted pile by having its bottom slightly hollowed. A cylindrical boring downward 1′ 9″ gave it the resemblance and similarity to a mortar. This mortar placed upon a pile to be driven remained there during the entire operation, its office being to receive the plunger, which traveled up and down in the frame and, in a measure, performed the work of the ordinary hammer. At its lower end it carried a 5-inch steel piston, two feet long, finished off with a ring somewhat larger, to fit tightly the 6-inch bore of the mortar. The weight of the plunger was about 2,400 pounds. It was hoisted in the frame by an engine and allowed to drop to the gun on the pile, into which one or two small powder cakes or cartridges, weighing from an ounce to an ounce and a half each, had been cast by a man stationed for this purpose upon one of the platforms. When the explosion takes place the pile is forced downward while the plunger is hurled upward. It may be held at any height by manipulating a brake at the lower platform, which compresses the frame guides against the grooves of the plunger. This operation can be repeated with considerable rapidity until the pile is driven as far as required. If men are well trained to the work and the operation perfectly understood, I grant that this driver might give good results; but in order to work well, the guides must be parallel and nearly in a vertical plane. Where this is not the case

*Of the Shaw type.

the plunger will bind in its movement and stick, which is also likely to happen when the piston is in the bore of the mortar and the charge has failed to go off.

In driving piles in this way for the dam, the constant bombardment and smoke would cause this peaceful locality to resemble a martial fort in warlike activity, when the great noise would cease suddenly on account of a disabled battery. In such an event the plunger usually got stuck in the mortar, and all the pulling of the little 12-horse-power portable engine (which, by the way, had to be purchased extra of the firm at an additional cost of $1,800) would fail to move it a particle. Then jack screws were in great demand and the efforts of the entire force were directed in parting these two inseparable objects. It sometimes took two or three days before the desired result was obtained, when the canonading would be again resumed to be similarly interrupted by the elective affinity existing between the plunger and the gun.

Nearly all the piles in the coffer-dam were driven with an ordinary driver, with a hammer weighing a ton and a half, mounted on a scow, which was moored and moved with considerable precision, as all the sheet-piling was driven on set ranges with great accuracy. The work done with the powder pile-driver amounted to a mere experiment. Only 142 piles were driven in all out of the 1,900 that constituted the dam. For this purpose 900 lbs. powder-cakes, costing 37½ cts. a pound, were used, so that an expense of $2.37 for powder was incurred for each pile;—and during all that time steam was up and the engine of the pile-driver ready to hoist away.

I extract the following from a record of an experiment made with this driver:

The first pile was shot in May 6th, 1873. It was 45 feet long, 15 inches square, and driven 13′ 3″ by 29 blows until the hard bottom was reached. The first blow forced it 30 inches and the last blows from 1 to 1¼ inches, while the recoil of the plunger after each shot was uniformly from 2½ to 3, and never over 4 feet. From a record kept later on, when in better running order, a pile was struck 59 blows, going 10¼ inches into hard ground.

The recoil of the plunger in that case was from 10 to 15 feet, but the results obtained were not very good. The records, however, were not extensive enough to deduce any facts of value from them; all I can say is that practically this method did not prove superior to our ordinary way of driving the pile by a falling weight, not to speak of the disadvantages of the noise and the smoke.

Two of these drivers were purchased, as I have said, but only one was ever put together and used. Both of them now adorn a scrap pile on the navy yard, I have been told, and their history has been almost forgotten by those who knew of them seventeen years ago.

All the piles were driven with blunt ends, in no instance was the pile pointed or shod. To keep the top from brooming it was protected by an iron ring, and operated upon until the last blow of the hammer would drive it about $\frac{1}{4}$ inch, when it was cut off to correspond with the adopted height of the dam. In this way the piles were driven as much as forty feet, twenty of which were into the hard clay.

In the front of the dam the piling extended below the excavation of the pit from 6 to 16 feet, but in the wings the ends of the piles did not reach the bottom of the excavation throughout.

During the long years in which the dock pit was left to its fate, the coffer-dam did excellent service, as I have already stated, and when work was finally resumed, and the material removed within the immediate vicinity of the piling, to make room for the masonry of the tail end of the dock, I am not aware that it began to show signs of great weakness even then, although it may have given some just anxiety to the engineer then in charge, when the excavation encroached within unsafe limits, but by using good judgment in prosecuting the excavation and the laying of the masonry, and by giving it all the additional protection and support from the interior as the walls progressed during that critical period, there was no great danger to be apprehended at any time. When it was finally removed in 1886, it had seen a longer service than it was originally designed for.

A calculation of the stability of the front of the dam may be summed up with a few figures as follows:

Highest water level above hard bottom	35 feet.
Horizontal resultant of the pressure of water per running foot, from the highest level to the hard bottom	17 tons.
Mean height of clay filling above the hard bottom in the coffer-dam	35 feet.
Width of clay wall	32 feet.
Volume of clay per running foot	1120 cu. ft.
Weight of clay wall	56 tons.
Moment of overthrow	$17 \times 11.67 = 198$.
Moment of stability	$56 \times 16 = 896$.
Factor of safety	$4\frac{1}{2}$.

Of course the stability was in reality much greater, for the dam, as a continuous double pile structure, aside from its inert contents, has not been considered in this estimate.

While the coffer-dam was building, the excavation at the middle and head of the dock was carried on simultaneously. When the proper depths had been reached, the concrete was laid as a bed for the granite blocks. This bottom layer was from four to five feet thick under the floor, rising in graded steps, and offsets in conformity with the adopted cross-section of the dock. (See appended illustration.)

Many valuable experiments were made by Civil Engineer Brown with the marketable cements, and as to the most effective mixture of beton for the purpose in view. The composition as used consisted of broken stone (egg size), gravel and cement, taken in the proportions of 50%, 42% and 8% respectively. The volume of the mixture was about two-thirds of the total volume of the ingredients, and after tamping the mass was reduced to about five-eighths.

For making the concrete rapidly and effectively an apparatus was built which did very good work. The idea was taken from a similar contrivance used extensively in France. It consisted

of a system of chutes through which the ingredients were dropped and came in contact while descending, gravity being made use of in this method for incorporating the different materials. A platform at the upper edge of the excavated pit contained two hoppers closed by hinged trap-doors, one communicating with a vertical chute or box about two feet square, and the other with a chute of smaller dimensions inclined at an angle of 45 degrees, both leading to a third receptacle located at a middle platform about 20 feet below the upper one. In the vertical chute there were placed six curved plates attached to opposite sides, three to a side, inclined downward at an angle of 45 degrees, and about 2′ 6″ long, so arranged as to catch the descending mass and to turn it over and over while falling, by having these plates curved upward and downward alternately. Sheet-iron plates protected all the surfaces subjected to great wear. The inclined chute had no obstacle of this kind, but presented a free communication from the upper to the middle platform. In the hopper of the vertical chute the gravel and cement were placed in the required proportions, and saturated with water by a sprinkler attached to a reservoir immediately over it, until sufficiently moist. The hopper of the inclined chute was filled in the mean time with the broken stone to the proper amount, and this slightly moistened. At a word of command both traps were simultaneously opened, and their contents rushed downward. The gravel and cement were thoroughly mixed in their fall, and joined at the outlet a stream of broken stone coming down the incline, after which both masses of mortar and stone collected in the receptacle of the middle platform, about twenty feet above the bottom of the pit. A man stationed here inspected the mass, and if it appeared too dry, more water was added before throwing back the lever which opened the trap to another vertical chute leading to the lower outlet. This contained four flat catch-boards, similar in arrangement to those already described, intended for the purpose of incorporating the broken stone with the mortar while falling to the bottom of the pit. When the mass was finally discharged it was pretty good concrete ready for use. This mixer made batches of half a cubic yard at a time, the practical proportions for which were

six wheelbarrows of broken stone to five of gravel and half a barrel of cement.* It would make, on an average, about thirty cubic yards a day, which would allow eight minutes for one operation of the mixer when in good working order. The labor required to do this was about as follows: two carts to haul materials to upper platform, one weigher or tallyman, four men loading upper chutes, one tender at middle platform, and three shovelers at the bottom of the pit filling barrows, cars or other receptacles, while three men took it off and supplied five tampers. There was a water tender below, whose duty it was to keep the hardening mass at the proper moisture. The concrete was spread in layers from 10 to 12 inches thick and tamped down. It was kept wet constantly, and allowed to set before another layer was added. Rosendale cement was used for the lower courses, and Portland cement for the upper layer only, which came in direct contact with the granite floor blocks and steps.

Concrete laying was begun in May, 1874, and carried on with frequent interruptions for many years until the walls had been carried up the required height. Two mixers were generally in use at that time when operations were in progress. The broken stone weighed about 2,500 lbs. to the cubic yard, and was delivered in those days at prices varying from $3.50 to $4.50 per ton, if I remember correctly.† The gravel was worth about $2.50 a cubic yard, and weighed perhaps as much as the broken stone. Cements were purchased at marketable rates, Portland cement being worth $6.50 a barrel in 1874. The work was done by hired labor.

The amount of concrete in the dock may be estimated roughly at 37,000 cubic yards.

The first granite block was laid in the floor at the center of the circular head on December 1st, 1874, which was considered a memorable event in the history of the dry dock—the laying of the corner stone, so to speak.

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*This refers to Rosendale cement. When Portland cement was used, one barrel was taken for 1½ cubic yards of the ordinary concrete.

†A stone crusher was made use of subsequently for manufacturing this material on the yard.

The blocks were cut to patterns in conformity with the arch, which were furnished to the contractors who finished each stone at the quarry and delivered them on the navy yard ready for laying. These stones were furnished under different contracts at different prices, and were cut in the quarries at Crystal Lake, Pino, Rocklin, Folsom and Penryn. They were laid by hired labor. A derrick was used to swing them into place, where they were set to proper alignment and grade. Under each block a layer of thick grout was spread, consisting of sand and Portland cement in the proportion of three to one. This mixture was also poured in between adjoining blocks to fill the joints and to unite them.

If the dock had been finished in this way, it would have been a magnificent granite structure of imposing dimensions and elaborate detail. But there were many changes made after a great portion of the floor had already been laid, which were not an improvement upon the original design. Mr. Calvin Brown was retired from active service about that time, and the supervision passed into other hands. It was then carried out to widen the chamber eight feet, and in order to gain that distance the first broad altar, which had a tread of four feet, was made eight feet instead. Later on the width was increased five feet more on each side, by inserting five additional altars in the upper courses and reducing the rises of the fourteen upper steps correspondingly. This gave the advantage of eighteen feet extra width of chamber, but it completely destroyed the principle of the inverted arch, which had been so carefully considered in the design and preserved in the work so far done, and which, in theory at least, was a correct principle. It also involved the overhanging of the side walls of the dock (to what extent I do not know) that had been projected originally with an ample foundation for the full breadth of the masonry. (The appended cross-section illustrates all these alterations.)

Similar changes were made in the caisson-arch, to which I shall refer, and in this way the intended bond of the dock was vitiated from one end to the other.

I have already stated that the dock was never completed. The government of the United States concluded to turn it over

for service in a very unfinished condition, for, with the exception of the floor and the first rises, the granite had not been laid when the coffer-dam was taken away. Instead of the clean and smooth surfaces of the stone, the rough and sombre concrete beds extended a melancholy greeting to the eye for years; arising on each side like solemn monuments to the memory of political administrations, they proclaimed the munificence of this great country to its important public works—proclaimed it in majestic silence, for never could awful stillness have been more impressive, even in the Pharaonic sepulchres of the pyramids, than there in that Mare Island dry dock during those long periods of general decadence. It has only been within the last few years that the most sanguine mind could have entertained the thought of the final completion of this structure.

Whatever the faults may be that cause results of this nature in almost all works undertaken by the nation, they reflect but upon the government and its system of providing means for the construction and maintenance of the people's works. But these matters have been referred to so often, and are so well understood by all, that it is useless to make mention of them.

It is fair to add here that the mechanical work has always been executed in the very best manner.

About the year 1885 the principal part of the dock then in progress was the building of the so-called invert, or caisson chamber, with its entrance from the bay. It was constructed of immense granite blocks laid upon concrete masonry in conformity to the shape of the newly adopted caisson. The floor was made horizontal for a distance of 14 feet on each side of the dock axis, and a quadrant of a radius of 25 feet adopted to connect it with the face of the side wall, making the width of the entrance 78 feet. This agrees with the breadth intended, but the horizontal floor gives it an entirely different cross-section from the original plan of the inverted arch, to which the first design had given such prominence as I have already stated.

Two projecting shoulders in the masonry allow for the abutment of the caisson held by exterior pressure.

The caisson was built by the Union Iron Works, and differed from that first intended, and generally provided, by having

a deep keel of 18 feet, the main body of the vessel being just large enough to float it at any stage of tide. It was furnished with eight double wicket gates through the deep keel-plate (to be used in filling the dock chamber), and with balancing tanks at each end.

A suit has been pending as to the right of the U. S. Government to use this particular construction, which was claimed as protected by letters patent. After three years of trouble and litigation, and after the case was twice decided in favor of the patentee, the Navy Department has seen fit to remove from this caisson all those parts infringing upon the patent, which presents a fair evidence that the plaintiff has been able to assert certain legal rights.

In the condition in which the caisson is now, it has lost about half its utility, for the wicket-gates are barred, and can no longer be used in connection with the filling of the chamber, which has to be accomplished by the filling-culverts alone.

The drain-culverts were made of brick-lining, with invert bottom and arched top, seven feet high by four wide. They begin at two drain wells near the entrance arch and run along through the concrete walls on each side of the dock to the circular head, where they both join on the north side, to carry their contents in one culvert to the well-hole under the house, which contains the great pumps of the dry dock.

The discharge-culvert from the pump-well seemed to have been an after consideration, and was designed when the dock was nearing its present state. Its construction has been explained to me, and I have also heard very severe criticisms passed upon it by men whose judgment I know to be perfectly sound and trustworthy. As I have never had an opportunity to see this part of the work, I am not in the position to furnish facts from actual observation. The discussion may bring out this matter, as there are members of this society now with us who saw the progress of this construction.

The pumping machinery was made by a Philadelphia firm, who took the contract in 1884 for furnishing, delivering and erecting the pumps for the Mare Island dry dock.

For pumping out the chamber there were to be furnished two centrifugal pumps, with a mean capacity of 40,000 gallons per minute each, and a lift of from one to thirty-six feet. The pumps were to be worked by two separate vertical non-condensing engines, each directly connected with one of the pumps so as to form two similar and independent apparati. Each engine to develop sufficient power to perform the duty required of its pump, with fifty pounds pressure of steam in the steam cylinder. The contract included the furnishing of all the necessary suction and discharge pipes, and check-valves for controlling the flow of the water. The contractor was also to furnish a centrifugal drainage-pump of not less than 2,000 gallons per minute capacity, with a suitable engine, in addition to the large pumps for emptying the dock. These pumps were erected in 1885 and ready for testing long before the coffer-dam was removed, for, with the usual promptness of the government in all such cases, a considerable time was wasted before the gravity of the situation allowed the authorities to begin this work and to complete it. It *was* completed finally in 1886, when the test was made. The pumps have been accepted and must therefore have come up to the requirements of the contract.

To sum up these remarks I want to make a statement of the cost of this great structure, which will not prove uninteresting.

The original estimate itemized the probable expenditures as follows:

Coffer-dam	$ 93,000
Excavation and embankment	104,550
Tools and fixtures	70,000
Temporary buildings	7,500
Temporary drainage	25,000
Piling, capping and planking foundation of dock	100,280*
Concrete and asphaltum work	70,500
Culverts	45,609
Stone masonry	1,185,768
Caisson, culvert gates	109,608
Engine house, etc	123,000
Engine, boilers and pumps	125,000

*Not required in the construction.

Two pile-wharves	13,284
Removing coffer-dam and dredging	20,000
Contingent	50,000
Total	$2,143,099

The money appropriated to the year 1886 was $2,577,500, which included an expenditure upon an iron-plating shop of $111,350 that should be deducted, leaving $2,466,150 for the dock. To complete it another estimate called for $191,595, which was appropriated; and when that had been expended without the desired result, $80,000 more were asked in May, 1888, for the same purpose and allowed. If that *should* finish the work, it will have cost the small sum of $2,737,745, which overruns the original estimate about $600,000. We must remember that the dock was lengthened 40 feet and widened 18; but this additional length and increase of width, at the same rate, need not have cost more than $250,000.

With such figures as these it does seem wise not to advocate the system of permanent stone dry docks as a comprehensive design for the future, and we can see the justification of Mr. Brown's objection. If it were required, for instance, to build a mooring-basin containing six of such docks for the accommodation of our vessels, and we were to base our estimate on past experiences and say: "If one dry dock will cost $2,737,745, what will six dry-docks and one mooring-basin cost?" I don't think that we would build many mooring-basins with dry docks, for even this country could be bankrupted.

Compare this with the cost of European docks of similar dimensions.

The Mare Island dock measures about 530 feet between extreme ends, and has a width of entrance of 78 feet. The chamber is 461 feet long, 30 feet wide on the floor, and 122 feet at the coping—the coping being 36′ 6″ above the floor. At average high tide the depth of water is 31′ 6″ in the chamber, and 27′ 0″ in the entrance arch. It will accommodate a vessel of 75 feet beam and 21 feet draught at low water.

These dimensions compare favorably with the largest docks in England and France. The eastern dock at Southampton, with a length of 538 feet over all, a width of entrance of 80 feet,

and a depth of 20 feet, was built, in 1854, of brickwork with Portland copings, and is stated to have cost £53,000, say $265,000.

I could take numerous cases to illustrate how very expensive the granite dock at Mare Island has been,* not omitting to consider the costliness of the material, which was perhaps unnecessarily elaborate for the purpose. The material best adapted for construction is known to be hard-burned brick, because such masonry will be the closest that can be made. Large stone blocks are hardly in place, since it is possible to make a Portland cement mortar not only equal to, but in many cases exceeding in hardness that of stone. It would only seem necessary to trim the corners and the edges of the brickwork with granite.

Another instance of the cost of foreign docks is presented by the two new dry docks at Toulon, where six already in use proved insufficient. The dimensions of these docks are 416 feet long, 82 feet wide, and 31 feet deep. The bottom in this case gave a great deal of trouble, and led to the method of laying the foundation under compressed air. The beton masonry was built in an iron floating dock 470 feet long, 135 feet wide, with sides 62 feet high. The bottom pontoon was 23 feet deep, of this 7 feet belong to the air-chamber, which was divided into eighteen compartments. The masonry under the floor was over twelve feet deep. One of these docks was built in four years' time, although it proved a construction of the greatest difficulty, which gave constant unforeseen trouble. The cost of these structures, which was considered great, amounted to $750,000 apiece, of which $200,000 go to the floating dock alone.

The amount of money thus far expended upon the Mare Island dock is sufficient to build three Toulon docks, and leave a balance of nearly half a million dollars. Or, if we deduct the item of the granite from the total cost of the Mare Island dock, it will still leave a sum large enough to build both the Toulon docks, and have about $50,000 to spare, after all of which it is to be remembered that the Mare Island dock is not finished yet, and may cost still more.

*I have somewhere read that the Norfolk dry dock, built about 1830, after which this has been copied, has cost the Government something like $950,000.

TECHNICAL SOCIETY OF THE PACIFIC COAST.

INSTITUTED APRIL, 1884.

PROCEEDINGS.

(VOLUME VII.—No. 1.)

MINUTES OF MEETINGS.

ANNUAL MEETING.

January 24th, 1890.

President Marsden Manson in the chair.

In the absence of the Secretary, Mr. Keith, and Mr. Raymond, one of the judges, the chair appointed Mr. Vischer to act as Secretary, and Mr. Wagoner to act as teller with Mr. Behr.

After opening and counting the ballots, the tellers reported as follows:

"We, the tellers appointed to conduct the election of officers for the Technical Society of the Pacific Coast, January 24th, 1889, hereby certify that twenty-nine (29) ballots were cast, all being the regular ticket proposed, a copy of which is annexed, and that no other votes were given."

Signed:

LUTHER WAGONER,
H. C. BEHR.

Then followed a list of the elected officers, thus:

President, JOHN RICHARDS; Vice-President, Professor F. SOULE; Treasurer, JAMES SPIERS; Secretary, OTTO VON GELDERN; Directors, ROSS E. BROWNE, L. L. ROBINSON, HERMANN KOWER, S. HARRISON SMITH, HUBERT VISCHER.

The Secretary read the report of the Treasurer, which was referred to the Finance Committee.

No further business appearing, the meeting adjourned.

H. Vischer, Acting Secretary.

REGULAR MEETING.

February 14th, 1890.

Regular meeting called to order at 8 p. m., President John Richards in the chair.

The minutes of the last regular meeting were read and approved.

Mr. Ross E. Browne then read a paper prepared by him and Mr. H. C. Behr, entited "Dr. Pohlé's Air-Lift Pump." After an interesting discourse upon a series of experiments, made by the authors in connection with Mr. P. M. Randall, Civil Engineer, an illustration of the manner of manipulating the pump and of the principle involved, was given by a small model of the apparatus, prepared for the occasion by Mr. H. C. Behr.

The discourse gave rise to an interesting discussion in which many of the members took part.

After the discussion a vote of thanks to the authors was passed.

The President having appointed Messrs. Luther Wagoner and S. Harrison Smith tellers to count the votes cast for a number of new candidates for admission to the Society, they reported that the following gentlemen were duly elected:

As members:

Jas. W. Reid,
H. T. Bestor,
Geo. F. Schild,
Burr Bassell.

As associate:

Henry P. Dimond.

Meeting adjourned.

Otto v. Geldern, Secretary.

REGULAR MEETING.

March 7th, 1890.

Called to order at 8:30 P. M. by Mr. S. Harrison Smith, acting as chairman.

Two agents, representing the firm of Keuffel and Esser, brought a number of engineers' instruments to the notice of the Society, with the desire to have the new features of both surveying and drawing instruments pointed out to the members present. Mr. Hubert Vischer explained the samples submitted.

This occupied some little time, after which the regular business of the meeting was taken up.

It was ordered to dispense with the reading of the minutes of the last regular meeting.

The following publications were presented to the Society:

"Catalogue Keuffel and Esser," 1887.

"Explorer's and Assayer's Companion," by J. S. Phillips, M. E., presented by Geo. Spaulding & Co.

"A Treatise on Masonry Construction," by Ira O. Baker, presented by the author through the publishers.

"Transactions of the Kansas Academy of Science," 1887-88, by the Academy.

"Transactions of the Astronomical Society of the Pacific," 1889, by the Society.

The Secretary was instructed to acknowledge receipt and thank the donors.

The following applications for membership were read. For members:

J. G. Pohle, proposed by Ross E. Browne, Chas. F. Hoffmann and H. C. Behr.

Adam Edward Chodzko, proposed by H. C. Behr, J. Richards and E. J. Molera.

P. M. Randall, proposed by H. C. Behr, Ross E. Browne and Otto von Geldern.

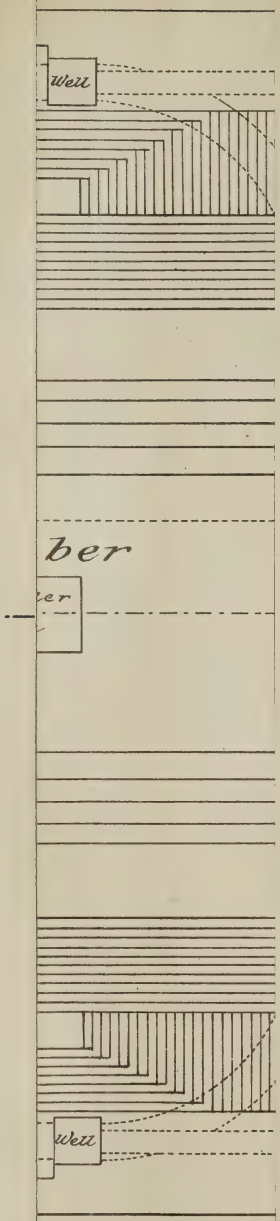
The Secretary then read a paper prepared by himself, en-

titled: "Notes on the Dry Dock and Coffer-Dam at the Navy Yard, Mare Island, California."

Not having had time to prepare the necessary drawings to illustrate the paper, the discussion on the subject was ordered postponed.

Meeting adjourned.

OTTO V. GELDERN, Secretary.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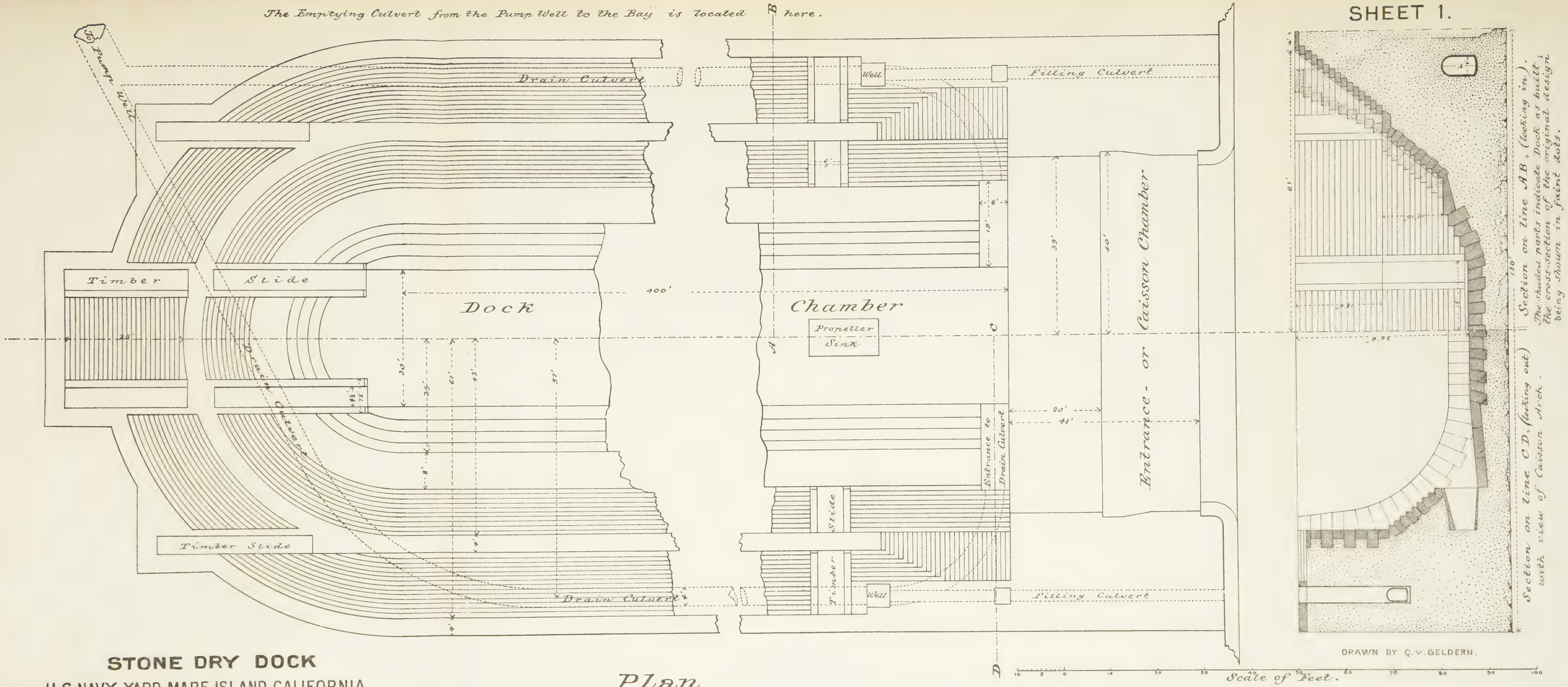
SHEET 1.



STONE DRY DOCK

U.S.NAVY YARD, MARE ISLAND, CALIFORNIA.

ORIGINAL DESIGN BY CALVIN BROWN, CIVIL ENGINEER.

Plan

TO ILLUSTRATE A PAPER BY O. v. GELDERN.

CONCRETE WALLS.

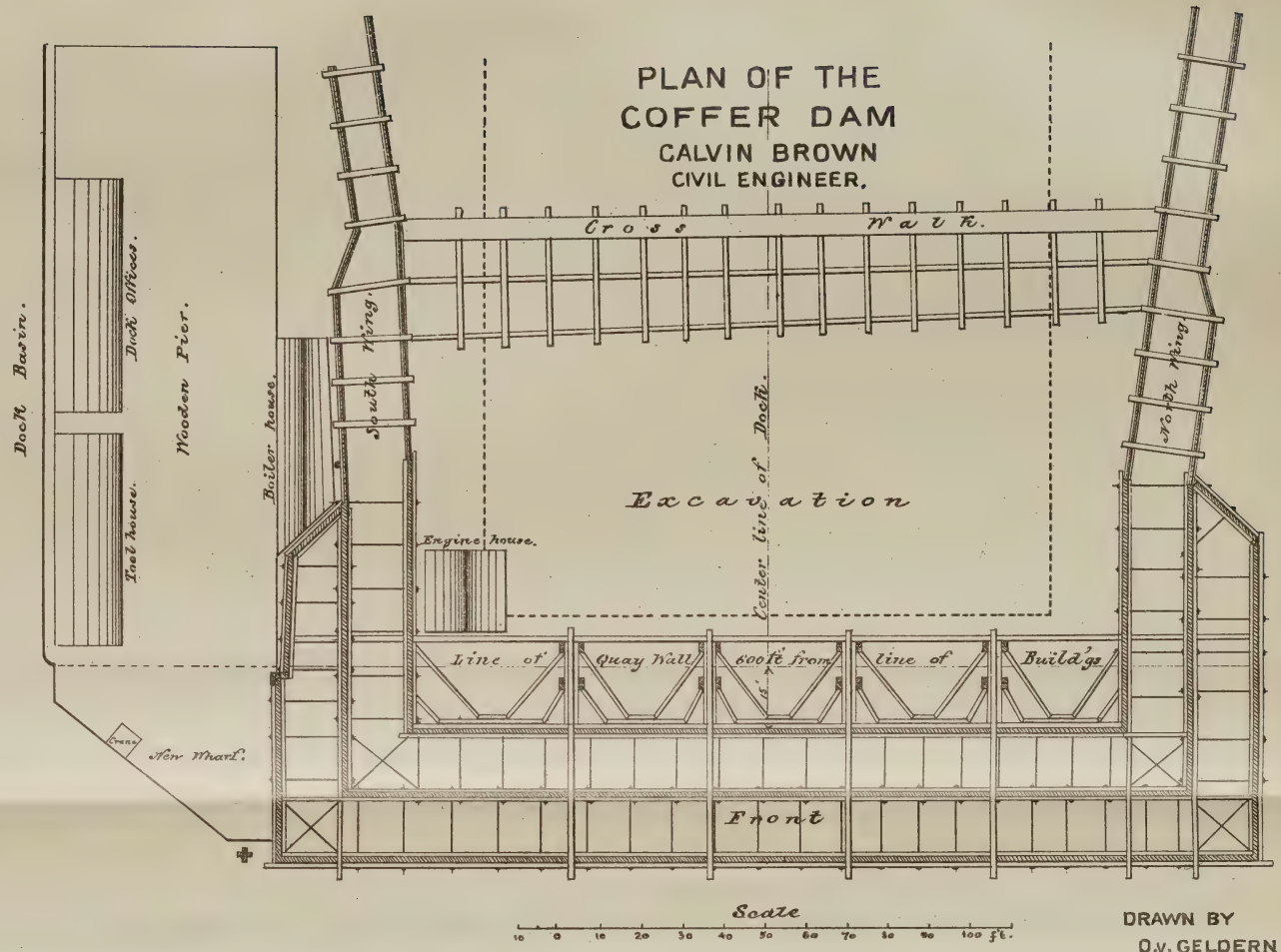
NIA.

ARTO. BRITTON & REY, S. F. TO ILLUSTRATE A PAPER BY O. V. GELDERN.

STONE DRY DOCK UNDER CONSTRUCTION, SHOWING CONCRETE WALLS.

U. S. NAVY YARD, MARE ISLAND, CALIFORNIA.

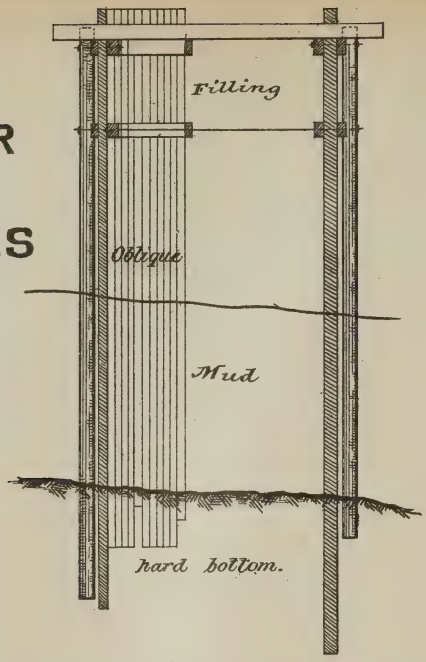
1885-86.



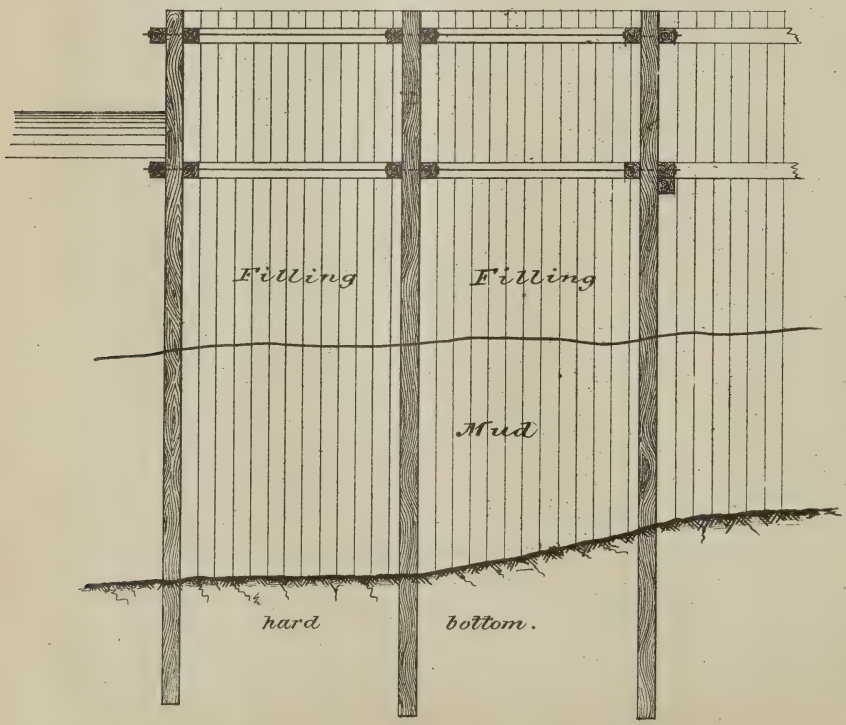
DRAWN BY
O.V. GELDERN.

SHEET 3.

COFFER DAM DETAILS



Section through the single portion of South Wing, looking in.



Section through the double portion of North Wing, looking out.

Scale

10 0 10 20 ft.

O. & G.

Filling

Filling

Layer of Mud

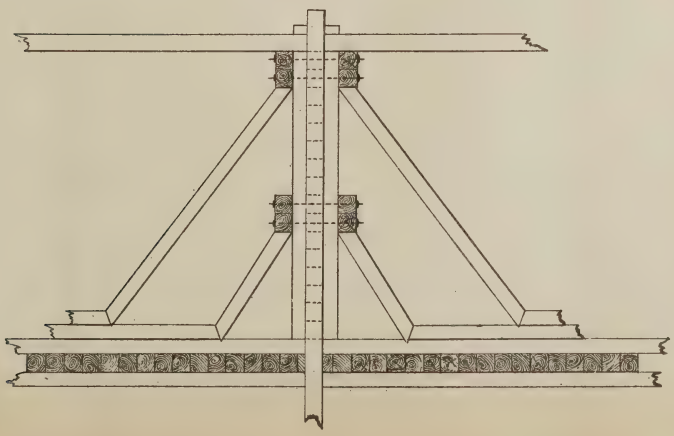
hard bottom.

Clay

Section through Front
showing Side Elevation of a Buttress.

Scale

10 5 0 10 20 30 ft.



Plan of a Buttress.

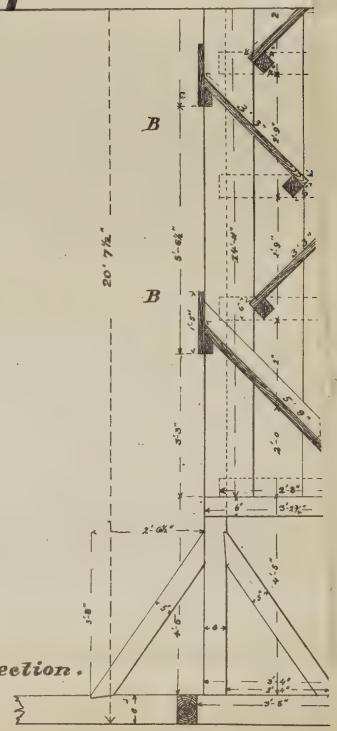
CONCRETE MIXING APPARATUS

Used in Construction
of
STONE DRY DOCK
at
U. S. Navy Yard, Mare Island,
California.

CALVIN BROWN, Civil Engineer.

O.v.G.

B.



Vertical Section.

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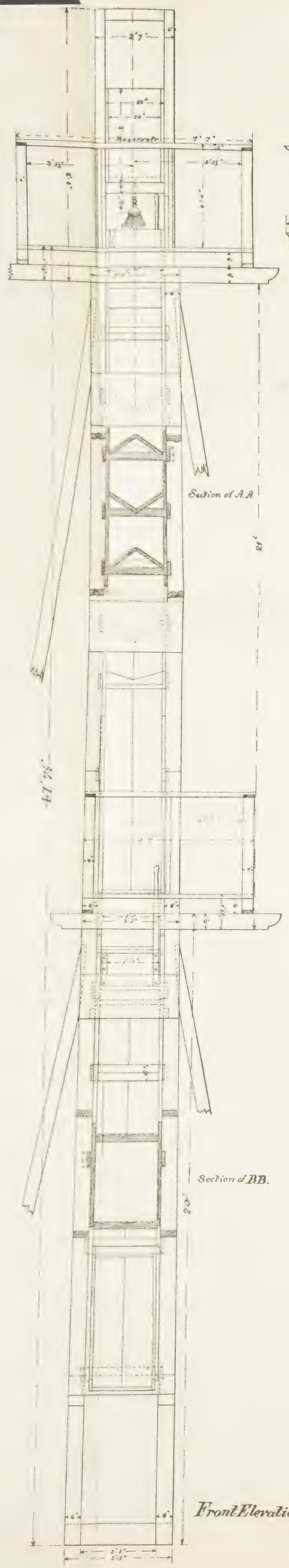
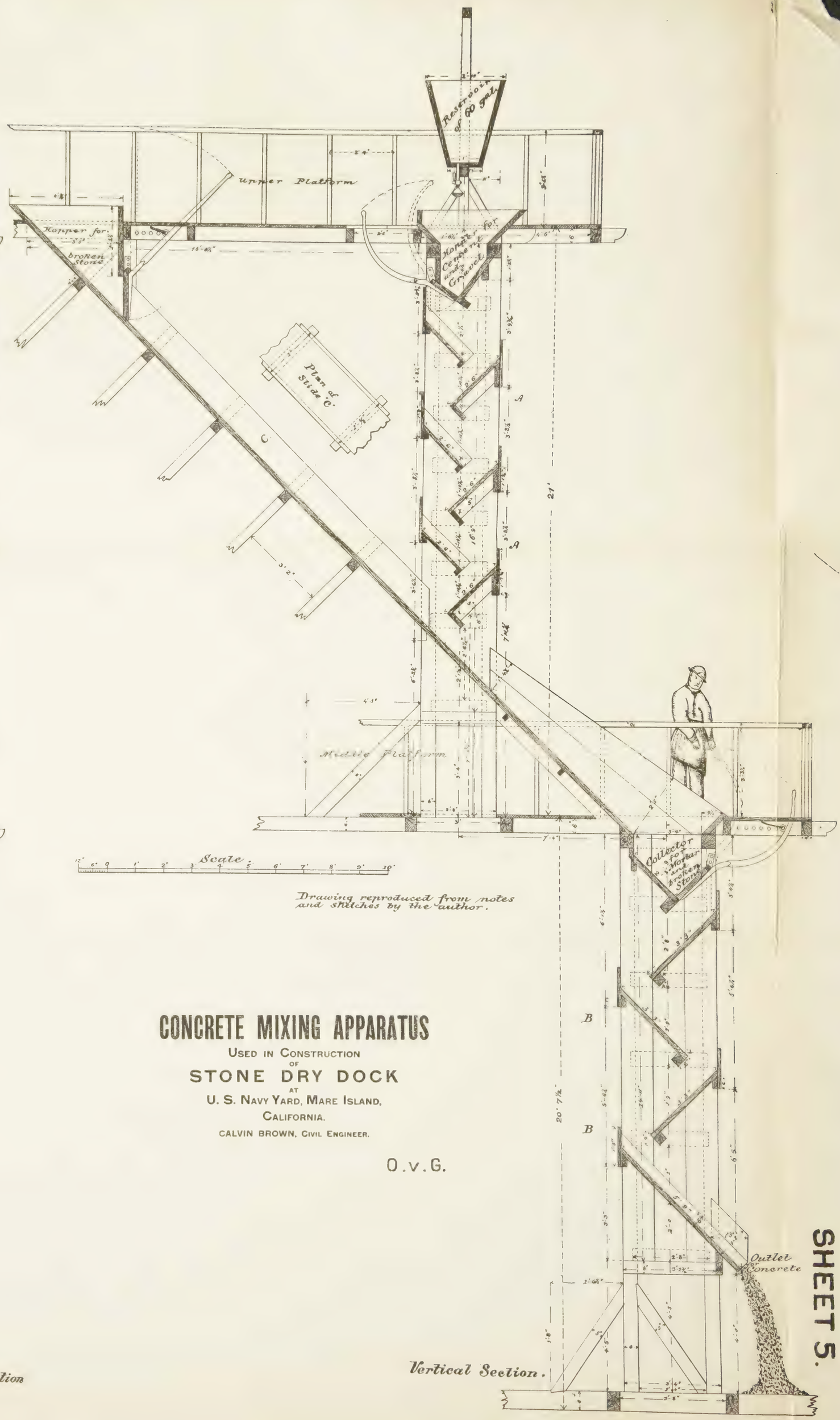




Drawing reproduced from notes and sketches by the author.

CONCRETE MIXING APPARATUS

USED IN CONSTRUCTION
OF
STONE DRY DOCK
AT
U. S. NAVY YARD, MARE ISLAND,
CALIFORNIA.

CALVIN BROWN, CIVIL ENGINEER.

O.v.G.

SHEET 5.

TECHNICAL SOCIETY OF THE PACIFIC COAST.

INSTITUTED APRIL, 1884.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the statements and opinions advanced in any of its publications.

(VOLUME VII.—APRIL, 1890.)

COFFER DAMS AND FLOATING CAISSONS.

BY RANDELL HUNT, C. E.

[Read April 4th, 1890.]

Coffer dams are used when it is necessary to pump out or excavate a foundation pit, and it is requisite to keep the work on the inside, dry. There is probably no other class of work in connection with foundations so little understood or so generally mismanaged, and in which all rules of good construction are so carelessly applied.

The result of this lack of knowledge has had a tendency to make the cost of this kind of work excessive; while the many failures to accomplish the proper coffer-damming of foundations prevents many a contractor from even making an attempt at it, and has in numerous cases magnified the difficulties to be overcome.

A coffer dam which has proved a success in one locality is not of necessity suited to another in which different conditions of soil exist. At the same time, however, a well designed dam, built for use under certain conditions of depth of water and *variety of soil*, is perfectly adapted for all similar work; and, indeed, it is possible to prescribe a standard set of designs to be of use for foundations generally of almost all characters.

Coffer dams are temporary structures, to last, generally, only

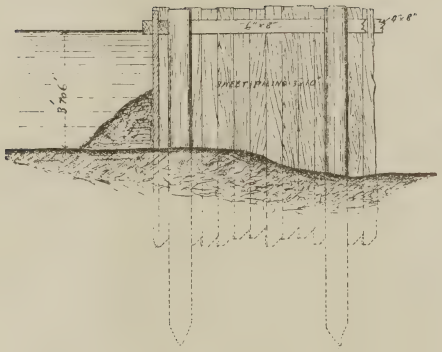
the short time while the permanent foundation inside of it is being constructed. It is, therefore, of the utmost advantage to reduce the cost of building them to the lowest possible amount.

COFFER DAMS FOR SHALLOW DEPTHS.

In still, shallow water, and where the soil of the bed of the river or stream is more or less impervious to quick infiltration, a mere embankment of clay or earth made with sufficient strength to withstand the pressure is generally the cheapest, and a very efficient coffer dam.

Clay makes the best dam, and will stand for a short time with considerable pressure against it without giving way. But there is no objection to the dam being made of a large proportion of sand and gravel mixed with but a small quantity of clay or stiff mud, which serves the purpose of making a concrete mass well calculated to keep out water. Such dams can be used up to considerable depth; but as their dimensions increase very rapidly in volume for but a limited increase in height, they usually become unwieldly and too great an obstruction to the stream to be used in such cases.

A very good coffer dam in depths not exceeding four or five feet, is to make a cheap crib with sides of planks of two inches in thickness (see Fig. 2), and with a width equal to the depth of water. In the pockets of this crib, which has been settled at the desired foundation site, earth, whether clay or other kind, is placed. This filling will generally sufficiently puddle itself in the process of being put in place. It has been the author's experience, in almost all the cases under his observation—which have been quite numerous—that there will be very little leakage in such a coffer dam, if the same is used when the sides of the crib touch the soil at its bottom edge pretty evenly all around. But in such a dam the *joint* between the filling material and the natural surface of the ground is the essential feature. It is seldom that the water will get through the filling above this joint, even if the sides of the crib are in no way tight; but at the bottom of the filling the least little seam, due to lack of close contact, will be apt to lead to an ever-increasing leak until the



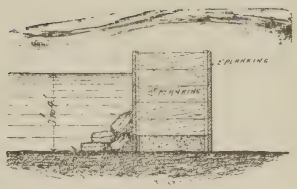


FIGURE 2

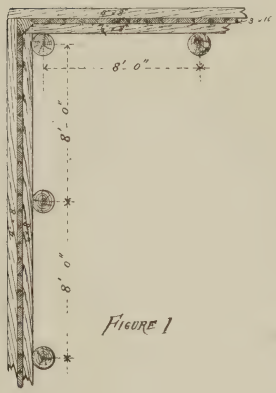


FIGURE 1

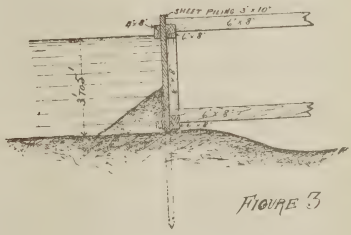


FIGURE 3

crib is often completely undermined. It is for this reason, as we have said before, that the earthen coffer dams are most successful when placed upon a soil which is not too porous. For, due to the pressure from the head of water on the outside of the dam, a soil which is loose, like most sands, will admit of a seapage, which invariably takes place just at the "joint" where the filled crib rests upon it, and the grains of sand flow into the dam until the undermining becomes serious. From this fact, some engineers prefer a filling of gravel and clay, for, as any material is drawn from under the crib, the gravel will fall down and at once fill up the void. We prefer, however, to use a more compact material in these small coffer dams—one which will cement itself closely to the ground in the first place, and which in itself will not permit of the leakage of coarser gravel.

If the soil is a light porous one on which the dam is to be constructed, either as an unprotected embankment or as a crib, the base should then be as broad as circumstances will permit, or often better, an entirely different kind of coffer dam should be used.

An earthen dam, without the protection of the crib described above, will need slopes of about one and a half to two horizontal, to one vertical, on both its outer and inner sides. For a dam four feet in height, therefore, with a width at top of four feet—and it should never be less than this—the width of the base will be from sixteen to twenty feet, requiring more room usually than can be spared for such work; besides which, the expense of constructing such an embankment would be much in excess of the crib made of simple planks.

Where there is a current which is strong enough to scour the foot of an embankment, or to eat its way under the edge of a crib, a useful expedient is to deposit a row of bags of gunny sack, or some other coarse strong material, filled with sand, or better, concrete, at the foot of the slope or at the edge of the crib. In the latter case it is still better to fasten canvas to the outer sides of the crib and then place the bags on top of it, and as close to the edge as possible; this method is shown in the figure.

We have intended the two different coffer dams described

above to be such as have often done good service in shallow water—depths not exceeding about four feet—but for greater depths they are better when modified somewhat. They are the types of the simplest kinds of dams and hardly call for the rather extended notice given them—but simple things are not always thought of, and our description may be of service to beginners at coffer damming.

SHEET-PILE COFFER DAMS.

A coffer dam should above all other things be as dry as it is possible to make it, and if made of sheet piling, only an experience with the numerous leaky places likely to show themselves when the dam has been pumped out, will be apt to convince one of the serious importance of untiring care in all the details of construction.

Figure 3 shows a section of a properly designed sheet-pile coffer dam, which if constructed in an impermeable soil in which the sheet piles can be driven without striking obstructions, such as stones or boulders or sunken logs, can be made to do good service for considerable depths.

The sheet piles are driven against waling pieces, which form a frame work about the foundation site, and serve as braces against the sides, to which the cross braces are attached. *The sheet piles should be continuous all around the dam, all of tongue and grooved or other matched lumber, without any break in the continuity of the matched material* except the unavoidable connections at the joining of the beginning and end together.

It is wrong to drive sheet piling between upright posts or piles placed at certain intervals—although this method is one of the old standard ones mentioned by engineering writers; at every post a bad and imperfect joint is likely to occur. The sheet piling may not be driven perfectly vertical, and the last one of a panel between posts must be made to fit tight against the side of the post, as well as making a close joint with the preceding sheet pile, which will be a very difficult thing to do under the circumstances. The use of these posts or piles is not apparent to us, for the sheet-piling if properly shaped and driven will make a close fit with one another and not require

the posts to aid in wedging them together. If it is necessary for the purpose of giving lateral support to the sides of the coffer dam to use large piles, or posts, it is far better to place them on the inside of the coffer dam and not interfering with the sheet-piles. It is well to place a waling piece on the outside of the sheet-piles at their tops, and driving them between this and the inside waling piece. Of course a dam constructed as described, if of any considerable extent and depth, will have some leakage; but it is surprising, how after the sheet piles get thoroughly soaked and swollen together, what little leaking there really is.

The frame-work of waling pieces should be carefully put in position before the driving of the sheet piles takes place. In many cases this can best be done by framing it together of the size desired, and separating the upper and lower belts of walings by small upright posts placed between them and joined to them. This frame can then be sunk at the desired location and the sheet pile driving commenced against it. If there is much excavation on the inside of the dam another set of side-pieces or walings can be put in after the excavation has proceeded a few feet and pushed down as low as desired. To make the dam complete, on the outside should be deposited a footing of clay or other impervious soil, if the same can be had conveniently and it does not form too great an obstruction to the work. This footing of clay will stop up any small hole in the dam due to bad workmanship.

Another very good form of coffer dam, and at the same time an inexpensive one, is made by driving sheet-piles against the outside of the timber crib which we have previously recommended for coffer damming in shallow water. When so made this crib and sheet-pile combination can be used in considerable depth of water, up to ten feet or more, if placed upon an impermeable soil. But the making of coffer dams with cribs is generally done by using cribs made of much heavier material than the thin planks recommended above, and further on will be more fully treated of.

Figure 1 shows a sheet pile coffer dam, made against a frame of large piles and waling pieces. This makes one of the most

serviceable of all dams for ordinary shallow water construction. The principle of a good sheet pile coffer dam should always be to make a good and stiff frame first, against which to drive the sheet piles; and whether made of the frame of walings, or cribs, or bottomless caissons, it should be well braced with cross-braces to prevent any distortion when the pumping and excavation takes place.

A regular plan should be decided upon, and carefully followed. It is only in this way that we can hope to be successful in foundation work. Haphazard construction without a clearly understood design will invariably result in much loss of time and money.

COFFER DAMS IN SANDY SOILS.

If coffer dams are built upon the simple plans which have been briefly sketched, and are founded in stiff and impermeable soils, or upon hard-pan or rock, there is no reason why they should not be successful.

Coffer dams upon sand and gravel are, however, structures of magnitude and great cost, whenever the head of water to be shut out becomes greater than four or five feet. Experience with coffer-damming in clay, river or harbor mud or upon solid foundations, is more apt to be of disadvantage to the engineer when he comes to found in sand than of benefit, for he is very likely to start construction on the same principles.

Most sands and gravel are more or less porous for almost unlimited depths. Therefore the simple crib or bottomless caisson with a single row of sheet-piling driven to moderate depths, even if the workmanship be of the best, will not prevent the whole bottom of the foundation from allowing the water to leak through like a sieve. Often the force of the leaking water sets the sand (particularly if rather fine grained) in motion, it becomes more or less quick, and the dam becomes a failure in short order.

To construct a coffer dam in sand with any certainty of success requires that the damming shall be perfectly done by carefully driving the sheet-piling, which must be well matched

together, to a very considerable depth below the level of the excavation on the inside of the dam. This depth must depend somewhat upon the character of the sand and its permeability; if light and not very compact, a rough rule of thumb is to have the sheet-piling next to the foundation, put as deep below the bottom of the excavation as the head of water above it.

When the head of water on the outside exeeds a few feet, the coffer dam is best made by driving two rows of sheet piles, spaced as many feet apart as the head of water, up to ten feet depth, and about three-quarters of the head for dams of greater height.

The space between the rows of sheet piles should be excavated to a depth from two to five feet below the line of the excavation on the inside of the dam, and then filled with carefully puddled material of clay, loam, or a mixture of either of these with coarse gravel.

The framework for the inside row of sheet piles is usually made as shown in Figure 1, of large piles, with waling pieces spiked to them. These large piles add lateral stiffness to the dam and avoid the need of too many cross-braces, which are more or less a hindrance to the work inside.

The labor of driving sheet piles is always one of the most expensive items of coffer dam work, and the double row of sheet piles, their increased length, and the extra labor required to drive them, increases the cost to a large extent. Often, however, an expensive coffer dam in the first construction is the cheapest in the end, as the cost of pumping is thereby much reduced.

The filling in such a dam as last described should depend somewhat upon whether the sheet-piling has been successfully driven so as to make a dam without any serious holes in it. If, from one cause or another, there are such bad places in the dam, it is then a very useful expedient to use as filling material, a certain amount of hay or manure, on top of which is deposited clay and gravel.

The effect of this hay and manure as filling material is, that it is drawn into the cracks and crevices by the leaking water and chokes them up. The gravel—and here is well exemplified why

this is to be preferred to clay or loam in such cases—follows down and presses against the hay, while at the same time it cannot escape.

In the case of a coffer dam made of a single row of sheet piles, a little hay and manure placed against the outside of the piles and then filled on the top with gravel and sand, is often of great use.

COFFER DAM USED IN CONSTRUCTING THE CHIPPEWA RIVER BRIDGE ON THE CHICAGO, BURLINGTON AND NORTHERN RAILROAD.

Figure 4 shows the coffer dam which was used in constructing the foundations for the pier for the draw span of the Chippepa river bridge. This bridge crosses the Chippewa river in Wisconsin about three-quarters of a mile above its mouth. It is founded in a moderately fine sand of unknown depth, borings as deep as fifty feet having been made without showing any other formation. The piers are placed upon piles, which are cut off about as deep as the river usually scours.

The coffer dam here shown, is given as an illustration, not of a success, but as a partial failure, the actual results which were expected to be attained not being realized. The original plans for the foundation of this pier contemplated the cutting off of the piles at an elevation three feet lower than shown in the drawing, but with the aid of three centrifugal pumps—one seven inch and two five inches in diameter—the water could only be lowered to a few inches below the tops of the piles as given.

Rather than delay the construction of the bridge, which was much needed by the railroad, the foundation was raised these three feet, and extra precautions were taken by brush mattresses and rip rap to guard against any possibility of scour in the future.

The coffer dam was made of three rows of sheet piles spaced about six feet apart, the inner row being braced by walings against large piles. The inside sheet piles were made of three-inch oak planks, matched together with a V-shaped tongue-and-groove; the two outside rows were of two-inch pine matched boards.

No dredging of the material between the different rows of sheet piles was done before the puddling was deposited.

The dam leaked badly through the joints between the sheet piling, and this leakage was greatest near the bottom of the excavation on the inside of the dam, the sheet piling showing many poor joints here; a large amount of water also came through the bottom of the foundation pit.

This coffer dam is instructive in showing clearly the mistakes of construction; briefly stated they were:

The use of sheet piling which was not thick enough to stand the hard driving without making irregular and open joints.

The sand between the rows of sheet piles should have been removed to a depth at least as low as the excavation inside the dam, before the puddling material was deposited.

The inside row of sheet piles should have been driven deeper.

With these precautions and good workmanship, there should not have been any trouble in reaching the desired level, although the leaking through the bottom of the foundation pit would in all probability have been considerable.

But is there not another lesson to be learnt from this coffer dam, besides that of how it could have been made water-tight? Does it not clearly show that it would have been far wiser to have made use of an entirely different plan to secure the desired end; not to have used a coffer dam at all, but to have used an open caisson, sunk on the pile tops after having previously removed the sand, and sawed off the piles at their proper elevation, by any of the simple means for doing such work?

The plans of this coffer dam and its details of construction were those of the contractors, who were not confined to any particular method in achieving the results called for by the specifications.

Professor Baker remarks,* in language which indicates practical experience: "Trying to pump a river dry through the sand at the bottom of a coffer dam is expensive. * * * Probably a coffer dam was never built that did not require considerable pumping, and not infrequently the amount is very great—so great, in fact, as to make it clear that some other method of constructing the foundation should have been chosen."

* "Masonry Construction," page 282.

CONSTRUCTION DIAGRAM
SHOWING

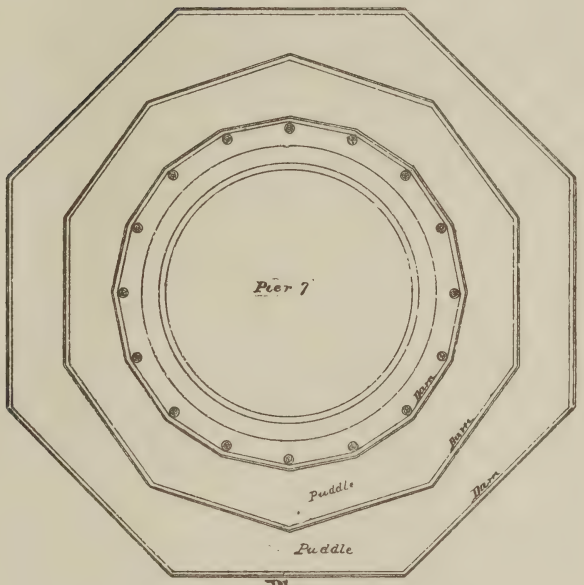
COFFER DAMS

AT

PIVOT PIER

CHIPPEWA RIVER BRIDGE

RANDELL HUNT,
ENG'R IN CHARGE.



Plan

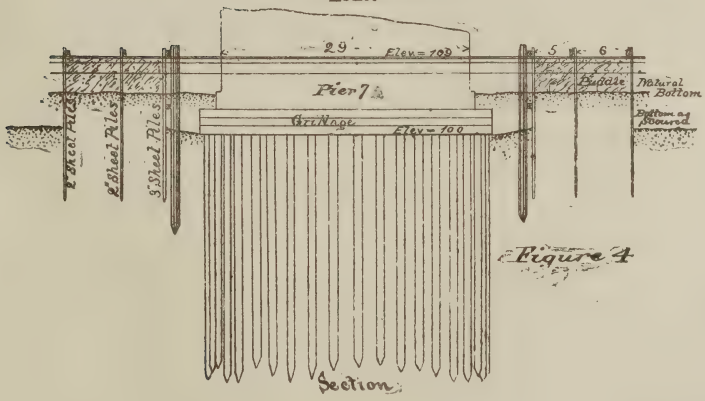


Figure 4

Section

THE USE OF CANVAS IN COFFER DAMS.

Canvas is often used in connection with coffer dams. In many cases it serves an admirable purpose, while in many others its efficiency is more imaginary than real. It is seldom necessary, in the author's opinion, to make use of it in sheet pile coffer dams except when the filling on the outside of a dam is liable to be washed away by a too rapid current. Then canvas nailed securely by its upper edge to the sheet-piling can be spread out over the filling, and its lower edge weighted down by heavy stones to the bed of the stream, and thus secure the dam from any scouring effects. In the same way it is often used on the lower edge of bottomless caissons which rest on rock or sandy soil.

An example of its proper use is given in another place, in the description of the coffer dam for the Aulne viaduct.

A coffer dam can be made of sheet-piling upon a rock foundation. In this case the framework against which the sheet piles are to rest, should be anchored in place by long steel rods, which are drilled into the rock at certain intervals. The wooden sheet piles are then put in place as in any other coffer dam, only to prevent their floating up they should be well spiked to the waling-pieces of the framework. The piles should be so driven that their ends will slightly bruise themselves against the rock. The dam should now be completed by a toe of clay filling on the outside, and if in further danger from a rapidly flowing current, this filling should be protected by canvas as mentioned above.

COFFER DAMS MADE OF CRIBS.

Very successful coffer dams have been made of cribs in connection with sheet-piling. The principle of these dams is exactly the same as those previously mentioned of sheet piles against a frame work. But they possess great stiffness, and are therefore well adapted for use in deep water.

FLOATING CRIB COFFER DAM.

In improving the navigation of the Schuylkill River in 1880,

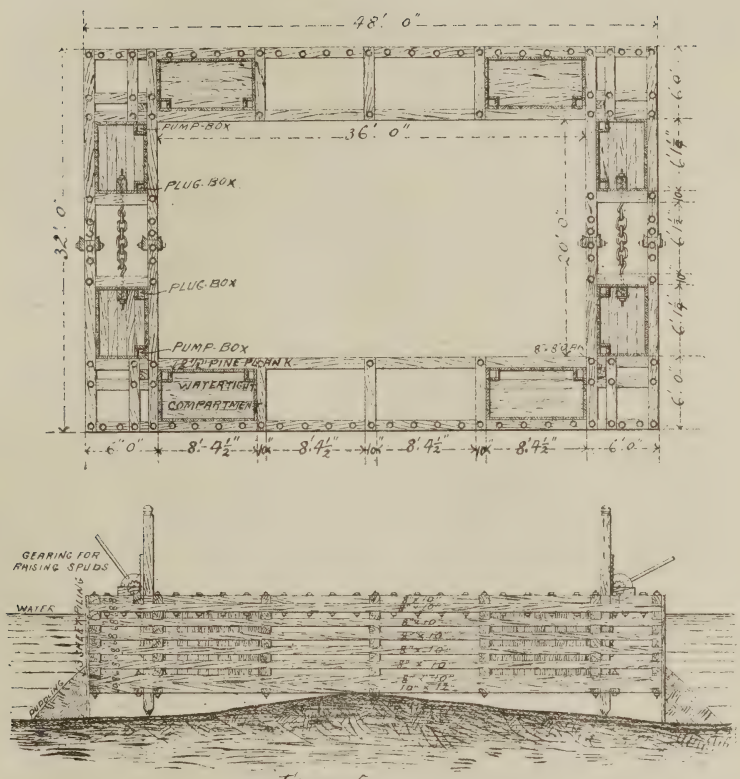

48' 0"
36' 0"
PUMP-BOX
PLUG-BOX
PLUG-BOX
PUMP-BOX
12" PINE PLANK
WATERTIGHT COMPARTMENT
32' 0"
20' 0"
6' 0"
6' 0"
8' 4½"
8' 4½"
8' 4½"
8' 4½"
GEARING FOR RAISING SPUDS
WATER
SHEET PILING
SHEET PILING

FIGURE 5

a floating coffer dam was used, a sketch of which is here given, Figure 5.

The outside dimensions were 32 by 45 feet, and the inside 20 by 36 feet. The dam was framed in two halves, cut longitudinally, for the purpose of passing the locks of the navigation—the two cribs, when coupled end to end, making a float 96 feet long by 16 feet wide.

This dam was novel in its design. Its being framed into halves, as above described, afforded facility for moving it, making it well adapted for use in constructing foundations for bridge piers, or other similar structures, after which it could be readily removed without injury to the dam itself, by uncoupling and removing each section. It also had water-tight chambers or boxes in the crib, by means of which it was floated from one point to another, and great facility afforded in settling it over obstructions.

When the crib was floating in the desired position, the long timbers marked B were let down into the river bed holding it in place. The water-tight compartments were then allowed to fill with water and the crib would sink to the ground. If additional weight was required to aid in sinking it these compartments would be filled with stone.

After the crib was well grounded sheet-piling was driven against it, on the outside, all around. Puddling of good, heavy, gravelly material was then placed around sheet-piling, after which the dam was pumped out.

The crib was framed eight feet high, and, usually, operated in seven and a half feet of water. The operation of removing the dam consisted in first pumping out the water-tight compartments and clearing them of stone. The sheet-piling was three and four inch jointed white pine, and was pulled up and used over and over again with but a small addition of new material required for each dam.

It is stated that the original cost of the dam, in 1879, was $1,128, and that it was used for several years. A 6-inch Andrews centrifugal pump was used for pumping, but at many locations the sheet-pilling was so tight that very little leaking occurred. Generally the pump was run three minutes out of every ten.

This dam required bracing inside while it was being pumped out; and during the prosecution of work a steam drill was used in removing the rock. The dam was a successful one and well adapted to the work for which it was designed.*

In our opinion it would have been an advantage to have had the outside of the crib made solid instead of with spaces between the timbers; in this case it would have been water-tight, and the duty of the sheet-piling would only have been to prevent leaking underneath the crib.

A good plan of coffer damming, when some protection is desired to remain permanently about a foundation, is to make it of cribs of timber, and to fill the same with rock, leaving the whole dam in place, and filling the space between the dam, and the foundation also, with rock.

COFFER DAMS WITH BOTTOMLESS CAISSONS.

An ordinarily built caisson with sides of plank well caulked, but without a bottom, sunk at a foundation site and surrounded with sheet-piling resting against it, makes one of the most serviceable and economical coffer dams. Particularly is this the case when the dam rests on rock and the toe of the sheet-piling is protected by clay, preventing leaking under it. The principle of such a dam is good; for it reduces the area of possible leaking to the space below the edge of the caisson, and the sheet piles have only to prevent leakage at this part of the coffer dam.

It should always be the aim in designing a coffer dam, to be as sure as possible that the leaking is reduced to a minimum; and while it is possible to drive sheet piles so close that they will not leak at the joints with one another, still it is not always likely to occur; and by using a bottomless caisson as described above, or a crib of which the sides are water-tight, we know in advance that we have at least that much of our coffer dam absolutely safe from leaks.

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* Proceedings of the Engineers' Club of Philadelphia, Vol iv, No. 4.

COFFER DAMS OF THE AULNE VIADUCT.

A very notable coffer dam of this description is that of the Viaduct of Aulne,* in France, of which Mr. Arnoux was the engineer, and shown in Figure 6. The piers in the river were three in number, and for two of them the difficulties of getting a foundation were serious. A dam below the bridge site made the depth of water about eighteen feet, besides which the high water of the sea made it about five feet higher. The foundation was a schistous rock, with very much inclined beds, of which it was necessary to break off the surface in order to reach the hard rock, and this, besides, was covered with a bed of mud and gravel. It was very necessary, in order to secure a pefect foundation, to be able to build the piers inside of a dry coffer dam. For this end, after having dredged off the soft material, a wooden bottomless caisson was submerged at each pier, 75 feet long by 33 feet wide, and the sides of which had been well caulked in advance. On account of the inequalities of the rock it was impossible to have the bottom of the caisson fit to it with any regularity; therefore, after it was sunk, between the two last courses of longitudinal braces of the caisson were driven vertical sheet piles well jointed.

A small dam of clay was placed against the feet of these sheet piles, and covered with strong canvas held in place by rock. The interior of the caisson was then drained, and it was found to be so free from leaks that a single pump working only two or three hours a day was able to keep the enclosure perfectly dry. There was no difficulty in taking off the soft parts of the schist and laying bare the hard parts in regular surfaces, and finally constructing the masonry up to high water.

In setting the caisson in place, the dam below the bridge was made use of. The caisson, after having been made on boats, was taken to the desired place and allowed to descend until it rested on some posts placed under its edge, by permitting the water of the dam to escape. Then, when the water rose, the boats which had been previously released from the caisson were made fast to it again near the top, and raising it permitted the

* *Procédés et Matéreaux de Construction*, A. Debauve, p. 67, Vol. ii.

33' 0"
WATER
PLANKING 3" THICK
PLANKING 2" THICK
SHEET PILING 3/4" THICK

FIGURE 6

posts under it to be removed. The water was once more made to fall, and the caisson descended until it rested in the desired position. No trouble was experienced in thus handling with great ease a mass of which the weight exceeded 75,000 kilogrammes.

THE KENTUCKY AND INDIANA BRIDGE.

At the bridge across the Ohio river at Louisville, the foundations were put in by various methods, without much system or definite plan. The same method was not used at any two piers, and hardly any of the foundations were worthy of note. At pier No. 5 a coffer dam similar in principle to that used at Aulne was employed.

A box, or bottomless caisson, was floated and settled into position. Sheet piling was driven to the rock on the outside of this box, and further protected by puddling placed against the sheet piles.

The lower four feet of the bottomless caisson was composed of 12 x 12-inch timbers, placed one on top the other and joined together by vertical bolts, while the top six feet was made of 10 x 10-inch timber, the outside being flush. Eighteen inches of gravel and three feet of slate were excavated at this foundation. The coffer dam was a very satisfactory one after the puddling had been placed around it, but this was found to be requisite before any success could be had in draining the dam.*

FLOATING CAISSONS.

In designing a structure, which must be founded below the water-line, the methods which will have to be employed to construct the foundation should be always kept clearly in mind. It is not wise nor does it, in our opinion, represent good engineering ability, to treat the designing of any particular class of work simply as an abstract problem, applying only scientific and correct rules in determining the most economical cross-section and plan for the structure itself, and to neglect the consideration of the means by which such design must be constructed. A simple

* Trans. Am. Soc. C. E., Vol. xvii.

truss span is of itself, generally, the most economical bridge which can be built across a stream; but often, by reason of the great expense necessary to erect the same, it is better to design in the first place the more complex and much more expensive span of the cantilever. In foundation work the same principles apply even to a greater extent, for usually the cost of the substructure of any extensive construction is a large proportion of the whole. But even if the item of cost is considered as not of particular moment, that of facility and quickness of construction is, in our present practical and rapid life, often of material advantage.

The principle of constructing a heavy structure upon a floating base, which simply by the action of gravity gradually sinks until the desired foundation is reached, is not a new one. In the earlier practice it was however confined almost entirely to open caissons made with a bottom of heavy timber and sides of plank like a scow; which was sunk by building the pier or other structure within it until the weight was sufficient to sink it upon piles or upon the natural foundation. On the introduction of compressed air, the caisson was modified so that below the first constructed base was introduced a working chamber, in which workmen could excavate while the floating structure above lowered itself. In the many devices of this method of huge cylinders of iron, or large cribs of timber and concrete, many of the greatest structures of modern times have been founded.

Excavating in compressed air, and particularly at considerable depths, is very expensive work, besides having more or less deleterious effects upon the men employed.

The invention of the Milroy excavator and the subsequent improvements of the same furnished a means by which in many cases compresed air could be dispensed with. The Milroy excavator is simply a small dredging apparatus, which as improved by Messrs. Anderson & Barr, consists of a dredging bucket made by means of four arms, which opened out are four pointed spades, and when closed together form a semi-circular receptacle. The weight of the dredge presses the points into the material to be excavated, while the action of raising the dredge first pulls the four arms deeper while at the same time closing

them. But the great usefulness of these dredges is from their portability, simply suspending them on a stout chain swung from a derrick or any other raising appliance, being all that is necessary.

In alluvial soils, sand, or even in clay of considerable stiffness, caissons formed of either great cribs, such as those of the recently constructed Poughkeepsie bridge across the Hudson River, or of great iron cylinders like those of the foundations of the Hawkesbury bridge in Australia, may be sunk to depths hitherto unthought of, by dredging out the material beneath them with Milroy excavators, and without the use of compressed air. The descent of the caissons is uniform and the work of constructing the piers on top goes forward simultaneously with the settling of the foundation to its desired level of rock or other hard material.

One of the marked features of modern engineering practice in the construction of submarine work, is in the employment of the open caisson wherever the conditions permit of its use.

In founding ordinary structures such as bridge-piers in shallow depths, which are to be placed upon piles, the cheap open box caisson affords a very efficient and economical method of attaining the desired result, and where it is practical it almost always is preferable to using a coffer dam about the foundation site, even if the head of water is but a few feet.

The open floating ceisson is an extremely simple device, and has proved remarkably efficient for structures of considerable size and in depths of water of twenty feet or more. The mathematics of the open caisson are equally as simple as its construction.

The sides should be made of timber of sufficient strength to withstand the pressure of the water, while care should be taken that the caisson is of proper dimensions, so that during its sinking it will remain in sufficiently stable equilibrium as not to be in danger of overturning.

If a vertical line drawn through the center of gravity, W, of the water displaced by the floating caisson intersects the vertical axis of equilibrium, A, B, *above* the center of gravity, G, of the caisson and its load, then it will be in stable equlibrium.

This point of intersection, *M*, is commonly called the metacenter of a floating body. If, however, the metacenter falls below the center of gravity of the caisson and its load, then it will upset. (See Figure 7; also Trautwine.)

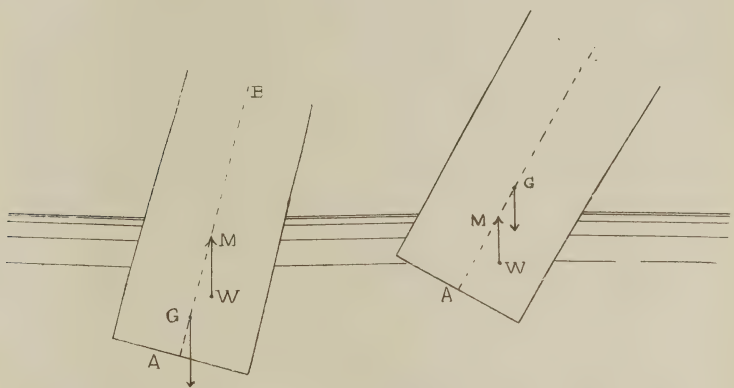


FIGURE 7.

Lack of precaution in checking the above simple calculation has led to several accidents in sinking caissons, a notable one being the overturning of a large floating crib caisson used in constructing a bridge pier foundation at Portland, Oregon.

CAISSON USED IN FOUNDING THE SEA WALL AT SAN FRANCISCO.

The sea wall now being constructed at San Francisco at the foot of Market street, consists of a concrete wall eighteen feet high, twelve feet wide at the base and six feet on top. It is founded on piles and backed by a relieving platform founded also on piles, to which the wall is anchored at intervals of ten feet. (See Figure 8.)

The original harbor mud was dredged out to a depth of about fifteen feet below the base of the wall, and this trench was filled with sand, before the foundation piles were driven.

The specifications required that after all the piles were driven a subsection of the work should be coffer-dammed, the water pumped out and the piles cut off and capped, and the wall built

as shown in the plan, all concrete being kept free from contact with salt water for seven days.

An attempt was made at constructing a coffer dam to enclose the first seventy-five feet of the wall. This coffer dam was not constructed on recognized principles or precedents for a work of such magnitude, and failed to be able to keep out the water.

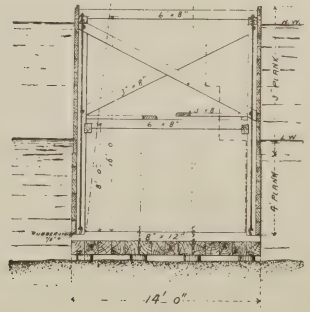
The author, at this stage of the work, was consulted by the contractors, and advised the abandonment of the coffer-dam method of constructing the wall, and substituting in place thereof that of sinking the wall by means of open floating caissons. After some little controversy permission from the Harbor Commissioners was obtained to use this system, on the contractors allowing a rebate to the State of some $5,000.

The work is now successfully going forward by this method. The caissons being used in the work are shown clearly in the accompanying drawings (Fig. 8). The total length of the wall to be constructed is four hundred and fifty feet. The number of caissons being used is seven, six of seventy feet length and one of thirty-four feet.

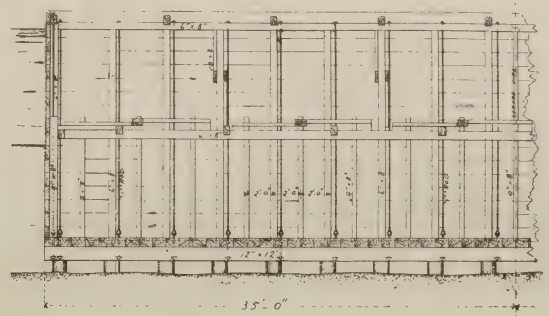
The depth of water in which they are sunk is from ten feet at low-water stage to seventeen feet at high water.

The caisson is made of a bottom of two courses of timber, one of twelve inches thickness and the other of eight inches, laid at right angles to one another, and bolted firmly to each other with three-quarter inch drift-bolts. The bottom course of twelve-inch timbers are also bolted to one another, with seven-eighth inch drift-bolts, which are made long enough to pass through three pieces.

The sides of the caisson are made of four and three-inch plank well spiked to the uprights or studding pieces, which are placed two feet between centers for a height of nine feet, and four feet between centers for the remaining top seven feet. These sides were fastened to the bottom by means of one-inch iron rods, which are made with a loop at the lower end and which connect with iron hooks which project through the bottom. These hooks are made of $1\frac{3}{8}$ round iron, with a nut and heavy washer on their lower ends, which are let into the timbers so as to be flush with the bottom. Partly let into the edge of the bottom plank, all



CROSS SECTION



SECTION THROUGH A-B.

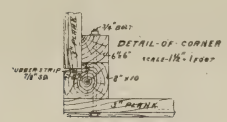
CAISSON

USED IN CONSTRUCTING THE SEA-WALL AT SAN-FRANCISCO, CAL

SCALE — 1/8" = 1 FOOT

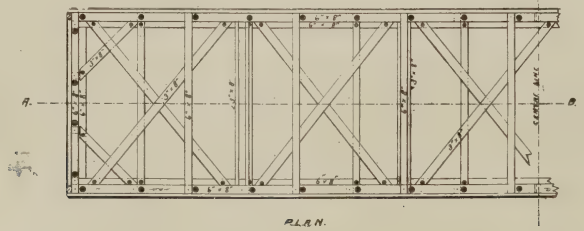
Randell Hunt

FIGURE 9 —



DETAIL-OF-CORNER

SCALE-1 1/2" = 1 FOOT



PLAN.

around the sides and ends of the caisson, is a piece of rubber one inch square, this rubber making the joint between the bottom of the caisson and its sides and ends.

The ends of the caisson are made so as to be able to separate them from the sides by simply withdrawing a few bolts which connect the two end posts together. A rubber strip is likewise used on the vertical seam between the ends and sides, as shown in the detail drawing.

Excepting the joint between the bottom and sides, and the just mentioned vertical joint at the corners, all other seams are carefully caulked with oakum throughout the entire caisson.

If the sides of this caisson were to be used but once, there is undoubtedly more material in them than needed, but they were designed to be used over and over again throughout the entire work.

As the bottom of a new caission is built and floated into position, then the rods which hold the sides in place on the previously sunk caisson are unhooked, and the entire sides and ends are lifted up by heavy blocks and tackle and swung over the new bottom. As the tide rises the bottom is carefully guided into its proper position until it joins itself to the sides; the rods are quickly looped over the hooks which have been previously placed in exact position in the new bottom, and screwed tight. The screwing up of the rods of course tightens the sides against the rubber strip and makes a close joint.

The moving of the sides of one caission on to the bottom of another is by no means the least interesting part of the work. They weigh about thirty tons, and the correct manipulating of them, to keep them from getting out of shape or distorted, so that each bottom will accurately fit in place, and make a close and tight piece of work with them, requires accurate workmanship and extreme care.

The sides of the seventy foot caissons have now been used in sinking four different caissons, and the last one showed no more leaking than the first one, which was practically nothing.

The caissons have proved perfectly satisfactory, and no mishaps with any serious consequences have occurred.

The connections between two sections of the wall, after they

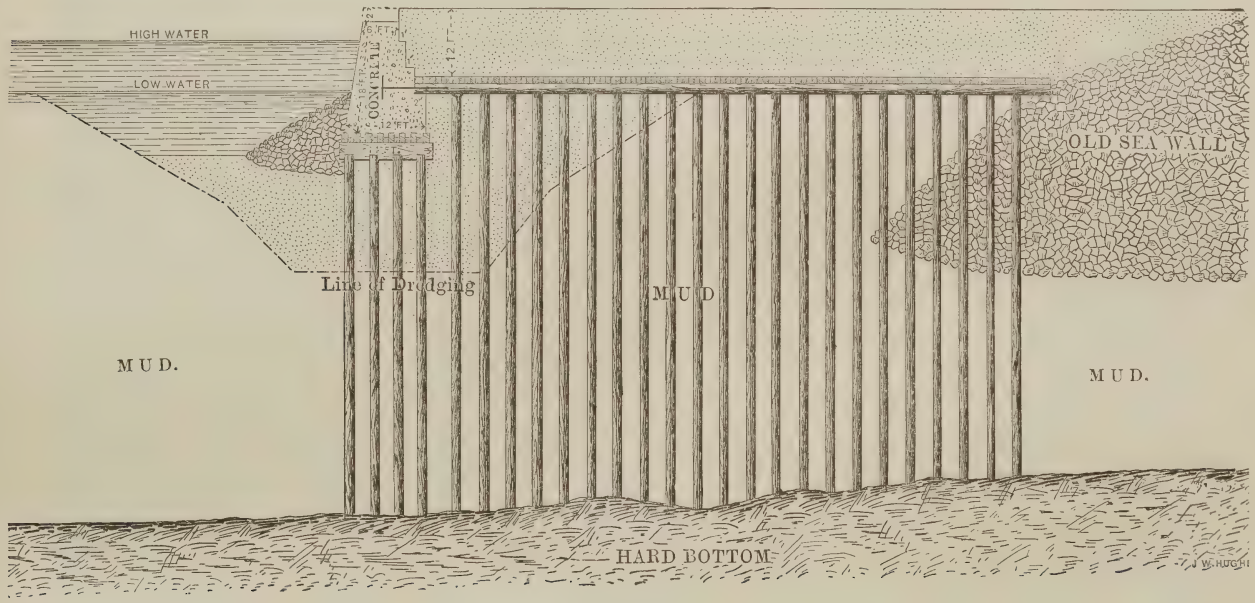

HIGH WATER
LOW WATER
CONCRETE
6 FT.
12 FT.
12 FT.
OLD SEA WALL
Line of Dredging
MUD
MUD.
MUD.
HARD BOTTOM
J. W. HUGHES

FIGURE 9.

have been sunk in place, is made by placing a coffer dam on top of the timber bottoms, which are made to press tightly together against a strip of rubber between them, by guiding the sinking of one caisson so that it presses against the previously sunk bottom.

The sides of these coffer dams rest against another piece of rubber, which is let into the edge of a timber imbedded in the concrete near the ends of each piece of wall.

A dovetail is left in the concrete wall at the ends, about two feet square; so that when two sections are joined together there will be no joint between them, and the wall is a continuous one from end to end.

The grillage is drift bolted to the piles of the foundation, by first locating their exact position upon the bottom of the caisson, and partly driving the bolts at these points. Pieces of gas-pipe are then placed over the bolts and the concrete deposited around hem, until the caisson comes to a firm bearing upon the piles; then a steel rod is let down each piece of gas-pipe and the drift bolt is driven home into the pile. These pipes are then pulled out of the concrete and used again in the next caisson.

TECHNICAL SOCIETY OF THE PACIFIC COAST.

INSTITUTED APRIL, 1884.

TRANSACTIONS.

(VOLUME VII—APRIL, 1890.)

MINUTES OF MEETINGS.

REGULAR MEETING.

April 4, 1886.

Meeting called to order at 8:15 P. M. by the President, Mr. John Richards.

The minutes of the last regular meeting were read and approved.

The following new members were declared elected: J. G. Pohlé, Adam E. Chodzko and P. M. Randall.

The following propositions for membership were read:

Adolph Lietz, proposed by H. C. Behr, Otto v. Geldern and H. Vischer.

Wm. M. Fitzhugh, proposed by Hubert Vischer, Luther Wagoner and Otto v. Geldern.

Joseph A. Sladky, proposed by H. C. Behr, John Richards and H. Kower.

Donations to the Society:

"Annual Report of the Chief of Engineers, U. S. A.," in four parts, by the Engineer Department.

Mr. Luther Wagoner presented the Society with a number of valuable books and papers, and Mrs. Specht donated seven or eight year's publications of several prominent European Technical Societies.

"Festschrift zum hundertjaehrigen Jubilaeum der Bergakademie zu Freiberg," presented by Otto v. Geldern.

The Secretary was instructed to return the thanks of the Society.

Mr. N. S. Keith then presented a statement, wherein he brought forth a claim of $300 for services as Secretary for the year 1889. Since the Finance Committee and the Board of Direction had returned the bill to him without taking any action upon it, Mr. Keith desired the Society to investigate the matter, and suggested the appointment of a committee to confer with him in this matter. Mr. Luther Wagoner moved that a committee of three be appointed to confer with Mr. Keith, to take some action upon the bill, and that this action of the committee be final. Seconded and carried.

The Chair then appointed Messrs. E. J. Molera, W. G. Raymond and G. W. Percy.

A communication from the American Society of Civil Engineers was read as follows:

New York, March 20th, 1890.

Dear Sir:

The following resolution has just been adopted at a meeting of the American Society of Civil Engineers:

Whereas, a new and higher dam is to be constructed immediately below the Bear Valley Arch Dam of California, the boldest arch dam in the world, in such a manner that said arch dam will be gradually relieved of strain, by letting in water below it, which process may be repeated several times, if desired, with but small waste of water; and, Whereas, these conditions afford a unique opportunity, never likely to recur, for determining the elastic yielding of said dam under strain and the coëfficient of elasticity of masonry as to which there is at present very imperfect information.

Resolved, that this Society request any of its members residing on the Pacific Coast, or any members of the Technical Society of the Pacific Coast able to do so, to make arrangements to cause minute observations to be made of the movements of the dam as strain may be gradually relieved or applied.

Resolved, Further, that the Secretary be requested to transmit a copy of the resolution to the Company owning the dam, with a request on behalf of the Society, that they will afford every facility to enable this unique opportunity to be properly availed of, and that they will in default of

other engineers offering to do so, themselves cause observations to be made by some competent observer, and cause them to be transmitted to this Society for publication in its transactions.

Your personal interest is particularly requested in this important matter, and you are earnestly asked to do what you can to secure, for future reference, all practicable data as indicated in the resolution.

Very respectfully,

JOHN BOGART,

Secretary Am. Soc. C. E.

Prof. Soulé moved that a committee of five or more be appointed to make the necessary preparations for such precise measurements as suggested, and to co-operate with any other committee appointed for the purpose from other societies. Carried.

The Chair appointed the following members:

Messrs. E. J. Molera, Frank Soulé, Luther Wagoner, Ross E. Browne and L. M. Clement.

The following gentlemen, not members, were added to the committee:

Adolph Lietz and Jos. C. Sala, both mathematical instrument makers.

Subsequently the name of John D. Isaacs, a member, was added to the list, making it a committee of eight.

Mr. Keith moved that the gentlemen not members of the Society be invited through the Secretary to co-operate with the others. Carried.

The Secretary was instructed to communicate with Messrs. Lietz and Sala.

Mr. Randell Hunt then read his paper on "Coffer Dams and Caissons" before the Society.

A vote of thanks was given the author, and upon motion the discussion of the paper was postponed for a future meeting.

Mr. Luther Wagoner explained some experiments made by stretching steel bars beyond their elastic limits, which causes a peculiar corrugated appearance of their surfaces. He called

the attention of the members to these markings, and stated that the experiments had been made some time ago by Lieutenant Gilmore, U. S. Navy, at the Union Iron Works, and that some interesting paper was in store for the Society.

It was announced that one of the Directors, Mr. Hubert Vischer, was about to leave for the Sandwich Islands, and that he was deserving of some notice for his energetic labors in behalf of the Technical Society.

Appreciation was acknowledged and a vote of thanks passed.

Meeting adjourned.

OTTO VON GELDERN,
Secretary.

TECHNICAL SOCIETY OF THE PACIFIC COAST.

SAN FRANCISCO, CALIFORNIA.

INSTITUTED APRIL, 1884.

TRANSACTIONS.

NOTE —This Society is not responsible, as a body, for the statements and opinions advanced in any of its publications.

(VOLUME VII.—JUNE, 1890.)

NAPIER'S DEFINITION OF A LOGARITHM AND ITS CONSEQUENCES.

BY PROFESSOR IRVING STRINGHAM, MEM. TECH. SOC.

Read June 6, 1890.

In order to put the student of mathematics early in possession of the fundamental processes of the differential calculus it has been customary, especially in England and America, to bring him to his destination by a sort of hop, skip and jump. This is done by sacrificing logical thoroughness in the presentation of fundamental principles. In France and Germany, however, this tendency is reversed and recent standard works, like those of Lipschitz,* Hoüel † and Harnack ‡ have broadened and deepened the foundations of the subject by a restatement and enlargement of the definition of number, and an elaborate treatment of the fundamental algoristic operations. This intro-

* *Grundlagen der Analysis.* Bonn, 1877.

† *Cours de Calcul Infinitésimal*, Paris, 1878.

‡ *Differential und Integral Rechnung.* Leipzig, 1881.

duces necessarily what M. Camille Jordan § calls the fifth arithmetical process, the operation of replacing a variable quantity by its limit, nor can we establish the elementary laws of differentiation by the algoristic, or analytical method except by first establishing, with the help of this fifth process in arithmetic (whose legitimacy is assumed as axiomatic), the rules of operation with exponential and logarithmic functions, including the binomial theorem for fractional and negative exponents, and hence involving the discussion of infinite series.

It is possible, however, to present the question in geometrical form, and in this way, independently of the possibility of representing the magnitudes involved, rationally or irrationally, in terms of number, to attach a tangible and legitimate meaning to the exponential function regarded as a strictly continuous magnitude in the geometrical sense, and thence to pass to the fundamental processes of differentiation for ordinary transcendental and all algebraic forms without resort to a discussion of infinite series. Such a method, as I here present it, returns to Newton's point of view of the differential calculus, though not to his form of statement. It in no way dispenses with the necessity for the consideration of the generalized definition of number and the development of the theory of so called continuous number, (algoristic continuity), as a basis for higher analytical discussions; but it enables us to postpone their introduction to a somewhat later period than is usual in the ordinary course of mathematical study.

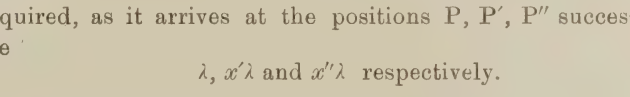
In what follows is presented a summary of the principles that lead directly from Napier's geometrical definition of a logarithm to the fundamental laws of logarithmic differentiation, substantially in the form in which I have given them by lecture during the past year and a half to students at the University of California. For the reason that I have never seen Napier's original works I am unable to say at what point in the development of the theory Napier stopped and his successors began. The form and order of statement is my own; and these, the distinguishing

§ *Cours d'Analyse de l'Ecole Polytechnique*, vol. iii, p. 554.

features of the method of presentation here given, will be most clearly brought out by reproducing the entire argument, involving therefore the restatement of familiar propositions; but I shall endeavor to present them in as concise a form as possible.

Napier's Definition.*

Suppose P and Q to be two points moving in a straight line, the former with a velocity proportional to its distance from an assumed origin, the latter with a constant



velocity. Let x represent the variable distance of P, y that of Q, from the origin, and let λ be the velocity of P when $x=1$, μ the constant velocity of Q. The velocities that P will have acquired, as it arrives at the positions P, P′, P″ successively, are

$$\lambda,\ x'\lambda \text{ and } x''\lambda \text{ respectively.}$$

The corresponding values of x and y are

$$x=\mathrm{OP}=1, \qquad x'=1+\mathrm{PP}', \qquad x''=1+\mathrm{PP}'',$$
$$y=0, \qquad y'=\mathrm{OQ}', \qquad y''=\mathrm{OQ}'',$$

Q being supposed to pass the origin at the instant when P has advanced to the position corresponding to $x=1$. Evidently the velocities of P and Q, at any epoch, are known as soon as the values of λ and μ are given, and their relative velocity, or, more explicitly, the velocity of Q relatively to that of P, as soon as the ratio of μ to λ is given. Based upon the foregoing graphical representation, the fundamental definitions of the logarithmic and exponential functions are as follows:

(I.) $\frac{\mu}{\lambda}$, a given value of which, say m, determines a system of corresponding distances $x, x', x'', \ldots$ and $y, y', y'', \ldots$, is called the *modulus* of the system

(II.) $y, y', y'', \ldots$ are called respectively the *logarithms* of

* MacLaurin, *Treatise of Fluxions*, vol. i, chap. vi, p. 158; Montucla, *Histoires des Mathematiques*, t. ii, pp. 16–17, 97.

$x, x', x'', \ldots$ with reference to the modulus m; and the functional relation between y and x is represented by the equation

$$y \equiv {}^{m}\log x \ .$$

It is evident that the form of this function remains unchanged for all coresponding values of x and y so long as the modulus remains constant.

(III.) The value of x that makes ${}^{m}\log x = 1$, in the system whose modulus is m, is called the *base* of the system.

(IV.) Corresponding to every logarithmic function defined by the equation $y \equiv {}^{m}\log x$, there is its inverse, called the *exponential* function by means of which x is represented as a function y. It is fully determined as soon as the base of the system is given. The exponential function to base b may be conveniently represented by

$$b^{y}$$

(V.) The logarithms whose modulus is unity are called *natural*, sometimes *Naperian*,* logarithms and the corresponding base is called *natural* or *Naperian* base. In this paper e will represent natural base and ln will be used as an abbreviation for natural logarithm, or logarithm to modulus 1.

Derivatives of the Logarithmic and Exponential Functions.

If we now take t as a standard variable of reference, representing time, we have at once for the velocities of P and Q respectively

$$\frac{dx}{dt} = \lambda x, \qquad \frac{dy}{dt} = \mu^{*},$$

and dividing the second equation by the first,

$$\frac{dy}{dx} = \frac{u}{\lambda}\,\frac{1}{x},$$

*It is well known that the numbers of Napier's original tables are not these natural, or so-called Naperian logarithms. The relation between them is expressed by the formula

$$\text{Naperian } \log x = 10^{7} \ln \frac{10^{7}}{x}$$

(See the Article on *Napier* by Glaisher in the *Encyclopedia Brittanica*.)

that is,
$$\frac{d\,({}^{m}\log x)}{dx} = \frac{m}{x},$$
the well known formula for the derivative of a logarithm.

Reversing this, so as to express dx in terms of y, we have

(since $x \equiv b^y$ and $y \equiv {}^{m}\log x$)

$$dx = \frac{x}{m}\, d\,({}^{m}\log x) = \frac{1}{m}\, b^y\, dy\,,$$

the formula for the differential of the exponential function b^y.

Relations Between Base and Modulus.

The relations between base and modulus are obtained as follows: Since $d \ln x = \frac{dx}{x}$, the primitive, or integral, of the equation $d\,({}^{m}\log x) = m\,\frac{dx}{x}$ may be written in the form

$${}^{m}\log x = m \ln x,$$

the arbitrary constant of integration being zero, in consequence of the relation ${}^{m}\log 1 = \ln 1 = 0$. If in the last equation b be substituted for x, the value of m is obtained in the form

$$m = \frac{1}{\ln b}$$

Hence in terms of the base of a system the logarithmic function is

$${}^{m}\log x = \frac{\ln x}{\ln b} = \log_b x\,.$$

If to x the value e be given, m is obtained in the form

$$m = {}^{m}\log e,$$

whence passing to the corresponding inverse function

$$b^m = e,$$

a relation that holds between the base and modulus of any system.

---

*It must be shown, of course, that to find the variable velocity of a point moving in a straight line, is the same problem as that of finding the derivative of the function that expresses the law of motion.

Returning to the equation

$$y = {}^{m}\log x = \frac{\ln x}{\ln b},$$

if for x we substitute its exponential equivalent, the equation takes the form

$$\ln b^{y} = y \ln b,$$

and more generally, if each member be multiplied by any quantity n, then

$${}^{n}\log b^{y} = y\,({}^{n}\log b),$$

which is the law of metathesis (of exponent and coëfficient) for logarithms.

From this we pass to the corresponding commutative law for exponents as follows: we have successively

$$y^{z} \ln b = y \ln b^{z} = \ln (b^{z})^{y},$$
$$= zy \ln b = z \ln b^{y} = \ln (b^{y})^{z};$$
$$\therefore\ (b^{y})^{z} = (b^{z})^{y}.$$

The Addition Theorem and the Law of Exponents.

The addition theorem for the logarithmic function follows very simply from its Naperian definition. Thus by means of the figure above described it is easily seen that

O	P		P′		P″
Q	1	Q′		Q″	

$$y' = {}^{m}\log x' = {}^{m}\log (1 + \mathrm{P\,P'})$$
$$y'' = {}^{m}\log x'' = {}^{m}\log (1 + \mathrm{PP''})$$
$$y'' - y' = {}^{m}\log \left\{ 1 + \frac{\mathrm{PP''} - \mathrm{PP'}}{x'} \right\} = {}^{m}\log \left\{ 1 + \frac{x'' - x'}{x'} \right\}$$

that is, $${}^{m}\log x'' - {}^{m}\log x' = {}^{m}\log \frac{x''}{x'}.*$$

In particular, since by definition ${}^{m}\log 1 = 0$,

* This fundamental property of logarithms might be stated as a definition and taken as the starting point of the theory. We should then define the difference between any two distances traversed by the point Q as the logarithm of the ratio of the corresponding distances traversed by the point P. This would include our former definition of the logarithm.

$$^{m}\log \frac{1}{x'} = {}^{m}\log 1 - {}^{m}\log x' = - {}^{m}\log x',$$

and therefore, writing x for $\frac{1}{x'}$,

$$^{m}\log x'' + {}^{m}\log x = {}^{m}\log (x'' x),$$

which is the addition thereon for logarithms.

The corresponding equations in terms of base are derived from the foregoing as follows: If b be the base of the system, then

$$x' = b^{y'},\ x'' = b^{y''},$$
$$x' x'' = b^{y'} b^{y''};$$

but

$$^{m}\log (x' x'') = {}^{m}\log x' + {}^{m}\log x''$$
$$= y' + y'',$$
$$\therefore\ x' x'' = b^{y' + y''} = b^{y'} b^{y''},$$

which is the fundamental law of exponents.

Logarithmic Differentiation.

The foregoing properties of logarithms once established, the rule of logarithmic differentiation is thereby formulated, and with it also the rules for differentiating all exponential functions. Thus the general process of logarithmic differentiation is expressed by the formula

$$\frac{d f(x)}{dx} = f(x) \cdot \frac{d \ln f(x)}{dx},$$

and this rule, together with the addition formula, applied to the general exponential function u^{v}, gives the result,

$$\frac{d (u^{v})}{dx} = v u^{v-1} \frac{du}{dx} + u^{v} \cdot \ln u \cdot \frac{d v}{d x},$$

and in particular, if v be constant, say $v = k$,

$$\frac{du^{k}}{du} = k u^{k-1}.$$

Thus we have established the fundamental theorem for the differentiation of algebraic forms without reference to the binomial theorem or to infinite series, and the quantities involved in

the formula may be looked upon as continuous magnitudes in the geometrical sense.

The definition which created the logarithm as an objective reality in mathematics, was published by Napier in 1614, more than half a century before the differential calculus was invented; but its author, though at the very threshold of a discovery greater than his own, and though he apparently had some intimation in his own mind of important consequences ahead, would doubtless have been astounded had he been told that he was laying the foundations of so lofty a superstructure as the differential calculus.

ERRATA.

Second asterisk (*) on page 66 refers to foot note on page 67.

In last equation of page 66 for u read μ.

TECHNICAL SOCIETY OF THE PACIFIC COAST.

INSTITUTED APRIL, 1884.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the statements and opinions advanced in any of its publications.

(VOLUME VII—JULY, 1890.)

FLOW OF WATER IN OPEN CHANNELS WITH TABLES BASED ON KUTTER'S FORMULA.

BY P. J. FLYNN, C. E., MEM. TECH. SOC.

Presented July 9th, 1890.

In a paper printed in the Transactions of the Technical Society for February, 1885, I gave tables and explained how, by their use, the application of Kutter's formula to the solution of problems relating to the flow of water in pipes and other closed channels could be simplified.

The present paper is based on the same principles and is intended to facilitate and simplify the computations relating to open channels in a somewhat similar way to that explained in the former paper for closed channels.

Kutter's formula for feet measures is:

$$V = \left\{ \frac{\frac{1.811}{n} + 41.6 + \frac{.00281}{s}}{1 + \left(41.6 + \frac{.00281}{s}\right) \times \frac{n}{\sqrt{r}}} \right\} \times \sqrt{rs} \quad . \quad . \quad (1)$$

and putting the first factor on the right hand side of the equation = c, we have:

$$V = c \times \sqrt{rs} = c \times \sqrt{r} \times \sqrt{s} \quad . \quad . \quad . \quad . \quad (2)$$

$$\sqrt{s} = \frac{V}{c \times \sqrt{r}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$c = \frac{V}{\sqrt{r} \times \sqrt{s}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

$$c \times \sqrt{r} = \frac{V}{\sqrt{s}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

$$Q = av = a \times c \times \sqrt{r} \times \sqrt{s} \quad . \quad . \quad . \quad . \quad (6)$$

$$Q = av = c \times a \sqrt{r} \times \sqrt{s} \quad . \quad . \quad . \quad (7)$$

$$V = \frac{Q}{a} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

$$a = \frac{Q}{V} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

In the formulæ and in what follows:

V = mean velocity in feet per second.
Q = discharge in cubic feet per second.
c = co-efficient of mean velocity.
s = fall of water surface h, in any distance l, divided by that distance $= \frac{h}{l}$ = sine of slope.

a = area in square feet of cross-section of channel.
p = wetted perimeter in lineal feet of channel.
r = hydraulic mean depth in feet = area of cross-section of channel in square feet a, divided by its wetted perimeter p in lineal feet $= \frac{a}{p}$

n = the natural co-efficient, the value of which depends on the nature and condition of the bed of the channel over which the water flows, or in other words its degree of roughness.

The tables give the separate values of the three factors on the right hand side of the equation

$$V = c \times \sqrt{r} \times \sqrt{s}$$

Table 1 gives the value of a, r, $\sqrt{r}$ and $a\sqrt{r}$ for different dimensions of channel and with side slopes of 1 to 1.

Tables 2, 3, 4 and 5 give the value of c and $c\sqrt{r}$ for channels having different values of n.

Table 6 gives the rate of slope and $\sqrt{s}$ for several longitudinal slopes or grades of channel.

By the substitution of these values in the formula already given problems relating to the velocity, discharge, dimensions and grade of channels can be solved with rapidity and accuracy.

The utility of Kutter's formula depends on the proper selection of the value of n. I may here mention that an extensive and very useful table of the value of n is given as an addition to the translation of Kutter by Messrs. Hering and Trautwine. This table will be found of great assistance to those using Kutter's formula, as it contains numerous examples of all values of n, and under various conditions of wetted surface, which will be found of great value in making a proper selection of the value of n.

The value of n is herewith given as compiled from the latest information from Jackson and also from Hering and Trautwine:

Canals in earth above the average in order and regimen—	$n = .0225$
Canals and rivers in earth of tolerably uniform cross-section, slope and direction, in moderately good average order and regimen and free from stones and weeds—	$n = .025$
Canals and rivers in earth below the average in order and regimen—	$n = .0275$
Canals and rivers in earth, in rather bad order and regimen, having stones and weeds occasionally and obstructed by detritus—	$n = .03$

CHANNELS HAVING THE SAME VELOCITY.

Other things being equal, channels having the same value of $\sqrt{r}$ will have the same velocity. For instance, in example 1 the channel has $\sqrt{r} = 1.482$, and a mean velocity of 2.75 feet per

second. Now all the channels in table 1, having $\sqrt{r}=1.482$ will have the same velocity of 2.75 feet per second when s and n are the same. Thus:

Bed	4 feet,	depth	4.25	feet,	$\sqrt{r}$	$=1.48$
"	5 "	"	4.00	"	"	$=1.486$
"	6 "	"	3.75	"	"	$=1.483$
"	17 "	"	2.75	"	"	$=1.481$
"	18 "	"	2.75	"	"	$=1.487$

For all practical purposes these five channels have the same velocity.

EQUIVALENT DISCHARGING CHANNELS.

Table 1 will be of use in finding equivalent discharging channels. Channels having the same or nearly the same value of $\sqrt{r}$ and a, have the same discharging capacity. For instance, in example 1, a channel 12 feet wide and 3 feet deep has an area of 45 square feet, and $\sqrt{r} = 1.482$. An inspection of table 1 will show some channels of a nearly equivalent discharge, thus:

Bed	10 feet,	depth	3.25	feet,	$\sqrt{r}$	$= 1.498$, $a = 43$
"	15 "	"	2.75	"	$\sqrt{r}$	$= 1.464$, $a = 48.8$

Again, a depth or width being first fixed, the corresponding width or depth to give the required discharge can be found after a few trials.

USE OF THE TABLES.

Example 1.—To find the Mean Velocity of a Channel.

What is the velocity of a channel having a bed width of 12 feet, depth 3 feet and side slopes of 1 to 1. Its grade is 5 feet per mile and its value of $n = .0275$?

In table 1, under a bed width of 12 feet and a depth of 3 feet, the value of $\sqrt{r} = 1.482$.

In table 4, under a value of $n = .0275$, and a slope of 1 in 1000 (which is the nearest slope to 5 feet per mile) and opposite $\sqrt{r} = 1.4$, we have

$$\sqrt{r} = 1.4, \quad c = 58.9$$
$$\text{“} \quad = 0.082, \; c = \quad 1.5^*$$
$$\therefore \quad \sqrt{r} = 1.482, \; c = 60.4$$

In table 6 the value of $\sqrt{s}$ corresponding to a slope of 5 feet per mile = .030773.

Now substituting the values of c, $\sqrt{r}$ and $\sqrt{s}$ just found in formula (2) we have:

$$V = c \times \sqrt{r} \times \sqrt{s}$$
$$= 60.4 \times 1.482 \times .030773$$
$$= 2.75 \text{ feet per second.}$$

As a check on this we have in table 4:

$$\sqrt{r} = \quad 1.4 \quad c\sqrt{r} = 82.4$$
$$\text{“} \quad = 0.082 \qquad \text{“} \quad = \quad 7.0^*$$
$$\text{“} \quad = 1.482 \qquad \text{“} \quad = 89.4$$

Substitute the values of $c\sqrt{r}$ and $\sqrt{s}$ in formula (2) and we have :

$$V = c\sqrt{r} \times \sqrt{s}$$
$$= 89.4 \times .030773$$
$$= 2.75 \text{ feet per second.}$$

Let us now compute the velocity by Kutter's formula (1)

$$V = \left\{ \frac{\dfrac{1.811}{n} + 41.6 + \dfrac{.00281}{s}}{1 + \left(41.6 + \dfrac{.00281}{s}\right)\dfrac{n}{\sqrt{r}}} \right\} \times \sqrt{rs}$$

substituting the values of n, s and r, we have—

$$V = \left\{ \frac{\dfrac{1.811}{.0275} + 41.6 + \dfrac{.00281}{.000947}}{1 + \left(41.6 + \dfrac{.00281}{.000947}\right) \times \dfrac{n}{\sqrt{r}}} \right\} \times 1.482 \times .030773$$

Computing this we find

$$V = 2.75 \text{ feet per second.}$$

---

* Obtained by interpolation between $\sqrt{r} = 1.4$ and $\sqrt{r} = 1.5$.

We thus see that the result by the rapid method of the tables is the same as that given by the much longer computation by the use of Kutter's formula. It will thus be seen what a great saving of time and labor can be gained by the use of the tables.

Example 2.—To find the discharge of a channel.

What is the discharge of a channel, 10 feet wide on the bottom, $2\frac{1}{2}$ feet deep, with side slopes of 1 to 1, a grade of 6 feet per mile and a value of $n = .0225$?

In table 1, under a bed width of 10 feet and opposite a depth of $2\frac{1}{2}$ feet, we find $a = 31.25$ sq. ft.—, $\sqrt{r} = 1.353$, and $a\sqrt{r} = 42.3$.

In table 2, with $n = .0225$ and under a slope of 1 in 1000, which is the nearest to 1 in 880 or 6 feet per mile, we get

$$\begin{array}{ll} \sqrt{r} = 1.3 & c = 70.6 \\ \text{“} \quad = 0.053 & c = 1.2 \\ \hline \sqrt{r} = 1.353 & c = 71.8 \end{array}$$

In table 6, the value of $\sqrt{s}$ for 6 feet per mile $= .03371$, substituting the values of a, c, $\sqrt{r}$ and $\sqrt{s}$ in formula (6) we have—

$$\begin{aligned} Q &= a \times c \times \sqrt{r} \times \sqrt{s} \\ &= 31.25 \times 71.8 \times 1.353 \times .03771 \\ &= 114.5 \text{ cubic feet per second.} \end{aligned}$$

As a check on this substitute the values of c, $a\sqrt{r}$ and $\sqrt{s}$ in formula (7) and we have:

$$\begin{aligned} Q &= c \times a\sqrt{r} \times \sqrt{s} \\ &= 71.8 \times 42.3 \times .03771 \\ &= 114.5 \text{ cubic feet per second.} \end{aligned}$$

Example 3.—To find the grade of a channel.

A channel has a bed width of 20 feet, a depth of 4 feet, side slopes of 1 to 1 and a value of $n = .025$. What grade must it have in order that its velocity may be 2.4 feet per second?

In table 1 we find that corresponding to a bed width of 20 feet and a depth of 4 feet that $\sqrt{r} = 1.751$.

In finding the slope of a channel it is necessary, first, to *assume* a value for the slope in order to obtain the value of c. Then a slope is *computed.* If this computed slope is so near the assumed slope that the value of c is the same for each of them, then the computed slope is the one required. If, however, the computed slope differs materially from the assumed slope, a new value of c for this computed slope must be found and the required slope computed a second time.

As a first approximation let us assume the slope to be 1 in 1000 and in table 3, with $n = .025$, we find when $\sqrt{r} = 1.751$ that $c = 71.5$.

Substituting the above value of c, $\sqrt{r}$ and V in formula (3)

$$\sqrt{s} = \frac{V}{c \times \sqrt{r}} \text{ we have}$$

$$\sqrt{s} = \frac{2.4}{71.5 \times 1.75} = .01917.$$

If we now look in table 6 we shall find that the nearest value of $\sqrt{s}$ to this is 1 in 2640, or 24 inches in a mile.

The assumed slope of 1 in 1000 is not correct, but as the table shows the value of c for the two slopes differs so little that the result found is practically correct. If, however, the values of c differed materially then the new assumed slope would be taken in the column headed 1 in 2500 and the value of c found from this, and the new slope computed again.

Now as a check on the above let us compute the velocity of the given channel with a slope of 24 inches per mile.

In table 6 the value of $\sqrt{s}$ corresponding to a slope of 24 inches per mile $= .019463$. Let us now substitute the values of c, $\sqrt{r}$ and $\sqrt{s}$ in formula (2)

$$V = c \times \sqrt{r} \times \sqrt{s} \text{ and we have}$$
$$V = 71.5 \times 1.751 \times .019463$$
$$= 2.44 \text{ feet per second—}$$

This velocity is greater than that required 2.4 feet per second and this is because the nearest value of $\sqrt{s}$ in the tables to .01917 is .019463, which is substituted in formula (2) above.

Example 4.—To find the value of c and n of a channel.

A channel is gauged and its perimeter is found equal to 26.48 lineal feet and its area equal to 63 square feet. Its discharge is 101.5 cubic feet per second, and the slope of its water surface is equal to 22 inches per mile—find the value of c and n.

$$r = \frac{a}{p} = \frac{63}{26.48} = 2.4$$

$$\sqrt{r} = \sqrt{2.4} = 1.55$$

$$V = \frac{Q}{a} = \frac{101.5}{63} = 1.61 \text{ feet per second—}$$

For a slope of 22 inches per mile $\sqrt{s} = .018634$. Substituting the values of V, $\sqrt{r}$ and $\sqrt{s}$ in formula (4)

$$c = \frac{V}{\sqrt{r} \times \sqrt{s}} \text{ and we have}$$

$$c = \frac{1.61}{1.55 \times .018634} = 55.8$$

A slope of 1 in 2500 is the nearest in the tables of n to 22 inches per mile. Now look under the different values of n and under a slope of 1 in 2500 and opposite $\sqrt{r} = 1.55$ and the value of c that is nearest to 55.8 will be found under the required value of n. In this case under a value of $n = .03$ and opposite $\sqrt{r} = 1.5$, we find the value of $c = 55.2$, which is the nearest value in the tables to 55.8. Therefore the required value of $c = 55.8$ and $n = .03$.

Example 5.—A canal is to discharge 150 cubic feet per second, with a mean velocity of 2½ feet per second. Its side slopes are 1 to 1 and its value of $n = .025$. Its depth is not to be greater than one-fifth of the bed width. What must be its bed width and depth and grade?

$$a = \frac{Q}{V} = \frac{150}{2.5} = 60 \text{ square feet.}$$

Now let us look in table 1 for a channel having an area of 60 square feet and whose depth is not greater than one-fifth of the bottom width, and we find it under a bed width of 17 feet and a depth of three feet, and at the same time we find $\sqrt{r}$ of this channel $= 1.534$. We must first take a slope by trial for the value of c. We assume a slope of 1 in 2500 in table 3 where $n = .025$, and opposite $\sqrt{r} = 1.5$ we find corresponding to $\sqrt{r} = 1.534$, that $c = 67.5$.

Substituting the values of c, $\sqrt{r}$ and V in formula (3)

$$\sqrt{s} = \frac{V}{c \times \sqrt{r}} \quad \text{we have}$$

$$\sqrt{s} = \frac{2.5}{67.5 \times 1.534} = .02414$$

The nearest slope to this given in table 6 is 3 feet per mile or 1 in 1760, but the actual slope 1 in 1716 can be found in table 7 of No. 84 of Van Nostrand's Science Series by the writer.

We therefore see that a channel 17 feet wide on bed, 3 feet deep, with side slopes of 1 to 1, and with a grade of 1 in 1716 complies with the conditions of the problem.

After the dimensions, &c., of the channel are fixed, it is advisable, in order to take every precaution to obtain accuracy that, as a final check, the work should be computed by Kutter's formula.

These tables will be found useful for the solution of a variety of problems not herein given, and the tables of slopes in Nos. 67 and 84 of Van Nostrand's Science Series by the writer will be found of great assistance in their application.

TABLE 1.

Channels having a Trapezoidal Section with side slopes of 1 to 1.

Values of the factors a = area in square feet; r = hydraulic mean depth in feet, and also $\sqrt{r}$ and $a\sqrt{r}$ for use in the formulæ:—

$$V = c \times \sqrt{r} \times \sqrt{s} \text{ and } Q = c \times a\sqrt{r} \times \sqrt{s}$$

Depth in feet.	Bed Width 1 foot.			
	a	r	$\sqrt{r}$	$a\sqrt{r}$
0.5	0.75	0.311	0.577	0.433
0.75	1.31	0.425	0.652	0.856
1.0	2.00	0.522	0.723	1.45
1.25	2.81	0.620	0.787	2.21
1.5	3.75	0.715	0.846	3.17
	Bed Width 2 feet.			
0.5	1.25	0.366	.605	.756
0.75	2.06	0.500	.707	1.46
1.0	3.0	0.621	.788	2.36
1.25	4.06	0.734	.856	3.48
1.5	5.25	0.841	.917	4.8
1.75	6.56	0.942	.971	6.4
2.0	8.	1.045	1.022	8.2
2.25	9.56	1.143	1.069	10.2
2.5	11.25	1.240	1.113	12.5
2.75	13.06	1.336	1.156	15.1
3.0	15.0	1.431	1.196	17.9
3.25	17.06	1.525	1.235	21.1
3.5	19.25	1.618	1.272	24.5
3.75	21.56	1.703	1.305	28.1
4.00	24.00	1.803	1.342	32.2

TABLE 1.

Channels having a Trapezoidal Section with side slopes of 1 to 1.

Values of the factors a = area in square feet; r = hydraulic mean depth in feet, and also $\sqrt{r}$ and $a\sqrt{r}$ for use in the formulæ:—

$$V = c \times \sqrt{r} \times \sqrt{s} \text{ and } Q = c \times a\sqrt{r} \times \sqrt{s}$$

Depth in feet.	Bed Width 3 feet.			
	a	r	$\sqrt{r}$	$a\sqrt{r}$
0.5	1.75	0.396	0.629	1.1
0.75	2.81	0.549	0.741	2.1
1.0	4.0	0.686	0.828	3.3
1.25	5.31	0.812	0.901	4.8
1.5	6.75	0.932	0.965	6.5
1.75	8.31	1.045	1.022	8.5
2.0	10.0	1.155	1.075	10.8
2.25	11.81	1.261	1.123	13.3
2.5	13.75	1.365	1.168	16.1
2.75	15.81	1.466	1.211	19.1
3.0	18.0	1.567	1.252	22.5
3.25	20.31	1.666	1.290	26.2
3.5	22.75	1.764	1.328	30.2
3.75	25.31	1.861	1.364	34.5
4.0	28.00	1.956	1.398	39.1
4.25	30.81	2.051	1.432	44.1
4.5	33.75	2.146	1.465	49.4
5.0	40.	2.333	1.527	61.1
	Bed Width 4 feet.			
0.5	2.25	0.416	0.645	1.5
0.75	3.56	0.582	0.763	2.7
1.0	5.	0.732	0.856	4.3
1.25	6.56	0.871	0.933	6.1
1.5	8.25	1.000	1.000	8.3
1.75	10.06	1.124	1.060	10.7
2.0	12.	1.243	1.115	13.4
2.25	14.06	1.357	1.165	16.4
2.5	16.25	1.468	1.211	19.7
2.75	18.56	1.576	1.255	23.3
3.0	21.	1.682	1.297	27.2
3.25	23.56	1.786	1.339	31.5
3.5	26.25	1.889	1.375	36.1
3.75	29.06	1.990	1.411	41.0
4.0	32.	2.09	1.446	46.3
4.25	35.06	2.189	1.480	51.9
4.5	38.25	2.287	1.512	57.8
5.0	45.	2.480	1.575	70.9

TABLE 1.

Channels having a Trapezoidal Section with side slopes of 1 to 1.

Values of the factors a = area in square feet; r = hydraulic mean depth in feet, and also $\sqrt{r}$ and $a\sqrt{r}$ for use in the formulæ:—

$$V = c \times \sqrt{r} \times \sqrt{s} \text{ and } Q = c \times a\sqrt{r} \times \sqrt{s}$$

Depth in feet.	Bed Width 5 feet.			
	a	r	$\sqrt{r}$	$a\sqrt{r}$
0.5	2.75	0.429	0.655	1.8
0.75	4.31	0.607	0.779	3.4
1.0	6.	0.766	0.875	5.2
1.25	7.81	0.915	0.956	7.5
1.5	9.75	1.054	1.027	10.0
1.75	11.81	1.186	1.089	12.9
2.0	14.	1.314	1.147	16.1
2.25	16.31	1.436	1.198	19.5
2.5	18.75	1.553	1.246	23.4
2.75	21.31	1.668	1.292	27.5
3.0	24.	1.780	1.334	32.0
3.25	26.81	1.889	1.374	36.8
3.5	29.75	1.997	1.413	42.0
3.75	32.81	2.103	1.450	47.6
4.	36.	2.207	1.486	53.5
4.5	42.72	2.412	1.533	65.5
5.	50.0	2.612	1.616	80.8
6.	66.	3.004	1.733	114.4
	Bed Width 6 feet.			
0.5	3.25	0.438	0.662	2.15
0.75	5.06	0.623	0.781	3.95
1.0	7.	0.793	0.891	6.2
1.25	9.06	0.950	0.975	8.8
1.5	11.25	1.098	1.048	11.8
1.75	13.56	1.238	1.113	15.1
2.0	16.	1.373	1.172	18.8
2.25	18.56	1.502	1.226	22.8
2.5	21.25	1.626	1.275	27.1
2.75	24.06	1.747	1.321	31 8
3.0	27.	1.864	1.365	36.9
3.25	30.06	1.979	1.407	42.3
3.5	33.25	2.091	1.446	48.1
3.75	36.56	2.201	1.483	54.2
4.0	40.	2.311	1.520	60.8
4.5	47.25	2.523	1.589	75.1
5.0	55.	2.731	1.653	90.9
6.0	72.	3.134	1.770	127.4

TABLE 1.

Channels having a Trapezoidal Section with side slopes of 1 to 1.

Values of the factors a = area in square feet; r = hydraulic mean depth in feet, and also $\sqrt{r}$ and $a\sqrt{r}$ for use in the formulæ:—

$$V = c \times \sqrt{r} \times \sqrt{s} \text{ and } Q = c \times a\sqrt{r} \times \sqrt{s}$$

Depth in feet.	Bed Width 7 feet.			
	a	r	$\sqrt{r}$	$a\sqrt{r}$
0.5	3.75	0.446	0.667	2.50
0.75	5.81	0.637	0.798	4.64
1.0	8.00	0.814	0.902	7.22
1.25	10.31	0.979	0.989	10.2
1.5	12.75	1.134	1.065	13.6
1.75	15.31	1.281	1.132	17.3
2.0	18.00	1.422	1.192	21.5
2.25	20.81	1.560	1.249	26.0
2.5	23.75	1.688	1.300	30.9
2.75	26.81	1.815	1.347	36.1
3.0	30.00	1.938	1.392	41.8
3.25	33.31	2.057	1.434	47.8
3.5	36.75	2.169	1.473	54.1
3.75	40.31	2.290	1.513	61.0
4.	44.00	2.403	1.550	68.2
4.5	51.75	2.623	1.619	83.8
5.	60.	2.838	1.684	101.0
6.	78.	3.254	1.804	140.7
	Bed Width 8 feet.			
0.5	4.25	0.451	0.672	2.85
0.75	6.56	0.648	0.805	5.28
1.0	9.	0.831	0.911	8.20
1.25	11.56	1.002	1.000	11.6
1.5	14.25	1.164	1.079	15.4
1.75	17.06	1.318	1.152	19.7
2.	20.	1.464	1.210	24.2
2.25	23.06	1.606	1.267	29.2
2.5	26.25	1.742	1.320	34.7
2.75	29.56	1.873	1.368	40.4
3.0	33.	2.002	1.415	46.7
3.25	35.56	2.069	1.439	51.2
3.5	40.25	2.269	1.506	60.6
3.75	44.06	2.368	1.539	67.8
4.	48.	2.486	1.577	75.7
4.5	56.25	2.714	1.647	92.6
5.	65.	2.936	1.713	111.3
6.	84.	3.364	1.834	154.1

TABLE 1.

Channels having a Trapezoidal Section with side slopes of 1 to 1.

Values of the factors a = area in square feet; r = hydraulic mean depth in feet, and also $\sqrt{r}$ and $a\sqrt{r}$ for use in the formulæ:—

$$V = c \times \sqrt{r} \times \sqrt{s} \text{ and } Q = c \times a\sqrt{r} \times \sqrt{s}$$

Depth in feet.	Bed Width 9 feet.			
	a	r	$\sqrt{r}$	$a\sqrt{r}$
1.0	10.	0.845	0.919	9.19
1.25	12.81	1.022	1.011	13.0
1.5	15.75	1.189	1.090	17.2
1.75	18.81	1.349	1.161	21.8
2.0	22.	1.501	1.225	27.0
2.25	25.31	1.650	1.284	32.5
2.5	28.75	1.789	1.330	38.2
2.75	32.31	1.927	1.388	44.8
3.0	36.00	2.059	1.435	51.7
3.25	39.81	2.189	1.479	58.9
3.5	43.75	2.315	1.521	66.5
3.75	47.81	2.439	1.562	74.7
4.0	52.00	2.560	1.600	83.2
4.5	60.75	2.796	1.672	101.6
5.0	70.	3.025	1.739	121.7
6.0	90.	3.466	1.862	167.6
	Bed Width 10 feet.			
1.0	11.0	0.858	0.926	10.2
1.25	14.06	1.039	1.019	14.3
1.5	17.25	1.211	1.100	19.0
1.75	20.56	1.375	1.173	24.1
2.0	24.	1.533	1.238	29.7
2.25	27.56	1.684	1.290	35.6
2.5	31.25	1.831	1.353	42.3
2.75	35.06	1.972	1.404	49.2
3.0	39.	2.110	1.452	56.6
3.25	43.06	2.244	1.498	64.5
3.5	47.25	2.375	1.541	72.8
3.75	51.56	2.502	1.582	81.6
4.0	56.	2.628	1.621	90.8
4.5	65.25	2.871	1.694	110.5
5.0	75.	3.107	1.763	132.2
6.0	96.	3.560	1.887	181.2

TABLE 1.

Channels having a Trapezoidal Section with side slopes of 1 to 1.

Values of the factors a = area in square feet; r = hydraulic mean depth in feet, and also $\sqrt{r}$ and $a\sqrt{r}$ for use in the formulæ:—

$$V = c \times \sqrt{r} \times \sqrt{s} \text{ and } Q = c \times a\sqrt{r} \times \sqrt{s}$$

Depth in feet.	Bed Width 11 feet.			
	a	r	$\sqrt{r}$	$a\sqrt{r}$
1.	12.	0.868	0.932	11.2
1.25	15.31	1.053	1.026	15.7
1.5	18.75	1.230	1.109	20.8
1.75	22.31	1.399	1.183	26.4
2.	26.	1.561	1.249	32.5
2.25	29.81	1.719	1.311	39.1
2.5	33.75	1.868	1.367	46.1
2.75	37.81	2.015	1.419	53.7
3.	42.0	2.156	1.466	61.6
3.25	46.31	2.291	1.513	70.1
3.5	50.75	2.428	1.558	79.1
3.75	55.31	2.561	1.600	88.5
4.	60.	2.688	1.640	98.4
4.5	69.75	2.940	1.715	119.6
5.	80.	3.182	1.784	142.7
6.	102.00	3.647	1.910	194.8
	Bed Width 12 feet.			
1.	13.	0.877	0.936	12.2
1.25	16.56	1.066	1.032	17.1
1.5	20.25	1.246	1.116	22.6
1.75	24.06	1.420	1.192	28.7
2.	28.	1.586	1.259	35.3
2.25	32.06	1.746	1.321	42.4
2.5	36.25	1.901	1.379	50.0
2.75	40.56	2.051	1.432	58.1
3.	45.	2.197	1.482	66.7
3.25	49.56	2.339	1.529	75.8
3.5	54.25	2.477	1.574	85.4
3.75	59.06	2.612	1.616	95.4
4.	64.	2.745	1.657	106.0
4.5	74.25	3.003	1.733	128.7
5.	85.	3.252	1.803	153.3
6.	108.	3.728	1.931	208.6

TABLE 1.

Channels having a Trapezoidal Section with side slopes of 1 to 1.

Values of the factors a = area in square feet; r = hydraulic mean depth in feet, and also $\sqrt{r}$ and $a\sqrt{r}$ for use in the formulæ:—

$$V = c \times \sqrt{r} \times \sqrt{s} \text{ and } Q = c \times a\sqrt{r} \times \sqrt{s}$$

Depth in feet.	Bed Width 13 feet.			
	a	r	$\sqrt{r}$	$a\sqrt{r}$
1.	13.	0.821	0.906	11.8
1.25	17.81	1.077	1.038	18.5
1.5	21.75	1.262	1.123	24.4
1.75	25.81	1.439	1.200	31.0
2.	30.	1.608	1.268	38.0
2.25	34.31	1.774	1.333	45.7
2.5	38.75	1.931	1.382	53.6
2.75	43.31	2.085	1.444	62.5
3.	48.	2.234	1.493	71.7
3.25	52.81	2.380	1.543	81.5
3.5	57.75	2.522	1.554	89.7
3.75	62.81	2.661	1.631	102.4
4.	68.	2.797	1.672	113.7
4.5	78.5	3.051	1.746	137.1
5.	90.0	3.316	1.821	163.9
6.	114.0	3.804	1.950	222.8
	Bed Width 14 feet.			
1.	15.	0.891	0.944	14.2
1.25	19.06	1.087	1.043	19.9
1.5	23.25	1.275	1.129	26.2
1.75	27.56	1.454	1.206	33.2
2.	32.	1.628	1.276	40.8
2.25	36.56	1.795	1.340	49.0
2.5	41.25	1.958	1.398	57.7
2.75	46.06	2.115	1.454	67.0
3.	51.	2.268	1.506	76.8
3.25	56.06	2.417	1.555	87.2
3.5	61.25	2.563	1.601	98.1
3.75	66.56	2.709	1.646	109.6
4.	72.	2.845	1.687	121.5
4.5	83.25	3.115	1.765	146.9
5.	95.	3.376	1.810	171.9
6.	120.	3.875	1.968	236.2

TABLE 1.

Channels having a Trapezoidal Section with side slopes of 1 to 1.

Values of the factors $a =$ area in square feet; $r =$ hydraulic mean depth in feet, and also $\sqrt{r}$ and $a\sqrt{r}$ for use in the formulæ:—

$$V = c \times \sqrt{r} \times \sqrt{s} \text{ and } Q = c \times a\sqrt{r} \times \sqrt{s}$$

Depth in feet.	Bed Width 15 feet.			
	a	r	$\sqrt{r}$	$a\sqrt{r}$
1.	16.	0.897	0.947	15.2
1.25	20.31	1.096	1.047	21.3
1.5	24.75	1.286	1.134	28.1
1.75	29.31	1.469	1.212	35.5
2.	34.	1.646	1.283	43.6
2.25	38.81	1.818	1.348	52.3
2.5	43.75	1.982	1.408	61.6
2.75	48.81	2.144	1.464	71.5
3.	54.	2.300	1.516	81.9
3.25	59.31	2.452	1.566	92.9
3.5	64.75	2.601	1.612	104.4
3.75	70.31	2.746	1.657	116.5
4.0	76.	2.888	1.700	129.2
4.5	87.75	3.165	1.779	156.1
5.	100.	4.431	1.852	185.2
6.	126.	3.941	1.985	250.1
	Bed Width 16 feet.			
1.	17.	0.903	0.950	16.1
1.25	21.56	1.104	1.051	22.6
1.5	26.25	1.297	1.139	29.9
1.75	31.06	1.482	1.217	37.8
2.	36.	1.662	1.289	46.4
2.25	41.06	1.835	1.354	55.6
2.5	46.25	2.005	1.416	65.5
2.75	51.56	2.168	1 472	75.9
3.	57.	2.328	1.526	87.0
3.25	62.56	2.484	1.576	98.6
3.5	68.25	2.635	1.623	110.8
3.75	74.06	2.783	1.668	123.5
4.	80.	2.929	1.711	136.9
4.5	92.25	3.211	1.792	165.3
5.	105.	3.484	1.866	195.9
6.	132.	4.004	2.001	264.1

TABLE 1.

Channels having a Trapezoidal Section with side slopes of 1 to 1.

Values of the factors a = area in square feet; r = hydraulic mean depth in feet, and also $\sqrt{r}$ and $a\sqrt{r}$ for use in the formulæ:—

$$V = c \times \sqrt{r} \times \sqrt{s} \text{ and } Q = c \times a\sqrt{r} \times \sqrt{s}$$

Depth in feet.	Bed Width 17 feet.			
	a	r	$\sqrt{r}$	$a\sqrt{r}$
1.	18.	0.908	0.953	17.2
1.25	22.81	1.111	1.052	24.0
1.5	27.75	1.306	1.143	31.7
1.75	32.81	1.495	1.222	40.1
2.	38.	1.677	1.295	49.2
2.25	43.31	1.853	1.361	58.9
2.5	48.75	2.025	1.423	69.4
2.75	54.31	2.193	1.481	80.4
3.	60.	2.354	1.534	92.0
3.25	65.81	2.513	1.585	104.3
3.5	71.75	2.667	1.633	117.2
3.75	77.81	2.819	1.679	130.6
4.	84.	2.967	1.722	144.6
4.5	96.75	3.255	1.804	174.5
5.	110.0	3.532	1.880	206.8
6.	138.0	4.062	2.015	278.1
	Bed Width 18 feet.			
1.0	19.	0.912	0.955	18.1
1.25	24.06	1.117	1.057	25.4
1.5	29.25	1.315	1.147	33.5
1.75	34.56	1.506	1.227	42.4
2.0	40.	1.691	1.300	52.0
2.25	45.56	1.870	1.367	62.3
2.5	51.25	2.044	1.430	73.3
2.75	57.06	2.213	1.487	84.8
3.	63.	2.379	1.542	97.1
3.25	69.06	2.541	1.594	110.1
3.5	75.25	2.697	1.642	123.6
3.75	81.56	2.851	1.688	137.7
4.	88.	3.002	1.733	152.5
4.5	101.25	3.296	1.810	183.8
5.	115.	3.578	1.891	217.5
6.	144.	4.117	2.029	292.2

TABLE 1.

Channels having a Trapezoidal Section with side slopes of 1 to 1.

Values of the factors a = area in square feet; r = hydraulic mean depth in feet, and also $\sqrt{r}$ and $a\sqrt{c}$ for use in the formulæ:—

$$V = c \times \sqrt{r} \times \sqrt{s} \text{ and } Q = c \times a\sqrt{r} \times \sqrt{s}$$

Depth in feet.	Bed Width 19 feet.			
	a	r	$\sqrt{r}$	$a\sqrt{r}$
1.	20.	0.876	9.936	18.7
1.25	25.31	1.123	1.060	26.8
1.5	30.75	1.323	1.150	35.4
1.75	36.31	1.516	1.231	44.7
2.	42.00	1.703	1.305	54.8
2.25	47.81	1.886	1.373	65.6
2.5	53.75	2.062	1.436	77.2
2.75	59.81	2.234	1.494	89.4
3.	66.	2.401	1.550	102.3
3.25	72.31	2.565	1.601	115.8
3.5	78.75	2.725	1.651	130.0
3.75	88.31	2.882	1.700	150.1
4.	92.	3.035	1.742	160.3
4.5	105.75	3.333	1.825	193.0
5.	120.	3.621	1.903	228.4
6.	150.	4.170	2.042	306.3
	Bed Width 20 feet.			
1.	21.	0.920	0.959	20.1
1.25	26.56	1.129	1.063	28.2
1.5	32.25	1.330	1.153	37.2
1.75	38.06	1.525	1.235	47.0
2.	44.	1.715	1.309	57.6
2.25	50.06	1.898	1.377	68.9
2.5	56.25	2.078	1.442	81.1
2.75	62.56	2.252	1.501	93.9
3.	69.	2.422	1.556	107.4
3.25	75.56	2.589	1.609	121.6
3.5	82.25	2.751	1.659	136.5
3.75	89.06	2.998	1.731	154.2
4.	96.	3.066	1.751	168.1
4.5	110.25	3.369	1.835	202.3
5.	125.	3.661	1.913	239.1
6.	156.	4.220	2.054	320.4

TABLE 2.

Based on Kutter's formulæ with $n = .0225$

Values of the factors c and $c\sqrt{r}$ for use in the formulæ:—

$$V = c\sqrt{rs} = c \times \sqrt{r} \times \sqrt{s} = c\sqrt{r} \times \sqrt{s}$$

$\sqrt{r}$ in feet.	1 in 20000		1 in 15840		1 in 10000	
	0.264 feet per mile.		0.3333 feet per mile.		0.528 feet per mile.	
	$s = .00005$		$s = .000063131$		$s = .0001$	
	c	$c\sqrt{r}$	c	$c\sqrt{r}$	c	$c\sqrt{r}$
.4	25.2	10.1	28.5	11.4	30.5	12.2
.5	33.0	16.5	34.2	17.1	36.3	18.2
.6	38.2	22.9	39.4	23.6	41.6	25.0
.7	43.0	30.1	44.2	31.0	46.4	32.5
.8	47.5	38.0	48.7	38.9	50.7	40.6
.9	51.7	46.5	52.8	47.6	54.8	49.3
1.	55.7	55.7	56.7	56.7	58.5	58.5
1.1	59.4	65.3	60.3	66.3	61.9	68.1
1.2	63.0	75.6	63.7	76.5	65.1	78.1
1.3	66.2	86.1	66.9	87.0	68.1	88.5
1.4	69.3	97.0	69.9	97.8	70.8	99.1
1.5	72.3	108.5	72.7	109.1	73.4	110.1
1.6	75.1	120.2	75.4	120.6	75.9	121.4
1.7	77.7	132.1	77.9	132.4	78.1	132.8
1.8	80.2	144.4	80.2	144.4	80.3	144.5
1.9	82.6	156.9	82.5	156.7	82.3	156.4
2.0	84.9	169.8	84.6	169.2	84.2	168.4
2.1	87.1	182.9	86.7	182.0	86.0	180.6
2.2	89.1	196.0	88.6	194.9	87.7	192.9
2.3	91.1	209.5	90.4	208.0	89.3	205.4
2.4	93.0	223.2	92.2	221.2	90.8	217.9

TABLE 2.

Based on Kutter's formulæ with $n = .0225$

Values of the factors c and $c\sqrt{r}$ for use in the formulæ:—

$$V = c\sqrt{rs} = c \times \sqrt{r} \times \sqrt{s} = c\sqrt{r} \times \sqrt{s}$$

$\sqrt{r}$ in feet.	1 in 7500		1 in 5000		1 in 3333.3	
	0.704 feet per mile.		1.056 feet per mile.		1.584 feet per mile.	
	$s = .000133333$		$s = .0002$		$s = .0003$	
	c	$c\sqrt{r}$	c	$c\sqrt{r}$	c	$c\sqrt{r}$
.4	31.6	12.6	33.0	13.2	34.0	13.6
.5	37.5	18.7	38.9	19.4	39.9	20.0
.6	42.7	25.6	44.1	26.5	45.2	27.1
.7	47.5	33.3	48.9	34.2	49.8	34.9
.8	51.8	41.4	53.1	42.5	54.2	43.4
.9	55.8	50.2	56.9	51.2	57.8	52.0
1.	59.4	59.4	60.5	60.5	61.2	61.2
1.1	62.7	69.0	63.7	70.1	64.4	70.8
1.2	65.8	79.0	66.6	79.9	67.2	80.6
1.3	68.7	89.3	69.3	91.1	69.8	90.7
1.4	71.3	99.8	71.9	100.7	72.3	101.2
1.5	73.8	110.7	74.2	111.3	74.5	111.8
1.6	76.1	121.8	76.4	122.2	76.6	122.6
1.7	78.3	133.1	78.4	133.3	78.5	133.5
1.8	80.3	144.5	80.3	144.5	80.2	144.4
1.9	82.1	156.2	82.1	156.0	81.9	155.6
2.0	83.7	168.0	83.7	167.4	83.5	167.0
2.1	85.3	179.8	85.3	179.1	85.0	178.5
2.2	86.8	191.8	86.8	191.0	86.4	190.1
2.3	88.1	204.2	88.1	202.6	87.7	201.7
2.4	89.5	216.5	89.5	214.8	89.0	213.6

TABLE 2.

Based on Kutter's formulæ with $n = .0225$

Values of the factors c and $c\sqrt{r}$ for use in the formulæ:—

$$V = c\sqrt{rs} = c \times \sqrt{r} \times \sqrt{s} = c\sqrt{r} \times \sqrt{s}$$

$\sqrt{r}$ in feet.	1 in 2500		1 in 1666.7		1 in 1000	
	2.112 feet per mile.		3.168 feet per mile.		5.28 feet per mile.	
	$s = .0004$		$s = .0006$		$s = .001$	
	c	$c\sqrt{r}$	c	$c\sqrt{r}$	c	$c\sqrt{r}$
.4	34.6	13.8	35.2	14.1	35.7	14.3
.5	40.5	20.3	41.1	20.8	41.7	20.8
.6	45.7	27.4	46.3	28.1	46.9	28.1
.7	50.4	35.3	51.0	36.1	51.5	36.1
.8	54.5	43.6	55.1	44.4	55.5	44.4
.9	58.3	52.5	58.8	53.3	59.2	53.3
1.	61.7	61.7	62.1	62.1	62.5	62.5
1.1	64.7	71.2	65.1	71.9	65.4	71.9
1.2	67.5	81.0	67.9	81.7	68.1	81.7
1.3	70.1	91.1	70.4	91.8	70.6	91.8
1.4	72.5	101.5	72.7	102.1	72.9	102.1
1.5	74.7	111.9	74.8	112.5	75.0	112.5
1.6	76.7	122.7	76.8	123.0	76.9	123.0
1.7	78.6	133.6	78.6	133.8	78.7	133.8
1.8	80.3	144.5	80.3	144.5	80.3	144.5
1.9	81.9	155.6	81.9	155.6	81.9	155.6
2.0	83.5	167.0	83.4	166.8	83.3	166.6
2.1	84.9	178.3	84.7	177.7	84.6	177.7
2.2	86.2	189.6	86.0	188.8	85.8	188.8
2.3	87.5	201.3	87.3	200.3	87.1	200.3
2.4	88.7	212.9	88.4	211.7	88.2	211.7

TABLE 3.

Based on Kutter's formulæ with $n = .025$.

Values of the factors c and $c\sqrt{r}$ for use in the formulæ:—

$$V = c\sqrt{rs} = c \times \sqrt{r} \times \sqrt{s} = c\sqrt{r} \times \sqrt{s}$$

$\sqrt{r}$ in feet.	1 in 20000		1 in 15840		1 in 10000	
	0.264 feet per mile.		0.3333 feet per mile.		0.528feet per second.	
	$s = .00005$		$s = .000063131$		$s = .0001$	
	c	$c\sqrt{r}$	c	$c\sqrt{r}$	c	$c\sqrt{r}$
.4	23.9	9.6	24.8	9.94	26.5	10.6
.5	28.9	14.4	29.9	14.90	31.7	15.9
.6	33.5	20.1	34.6	20.6	36.4	21.8
.7	37.9	26.5	38.9	27.2	40.7	28.5
.8	42.0	33.6	43.0	34.4	44.7	35.8
.9	45.8	41.2	46.7	42.1	48.4	43.6
1.0	49.4	49.4	50.3	50.3	51.8	51.8
1.1	52.8	58.1	53.6	59.0	55.0	65.0
1.2	56.0	67.3	56.8	68.1	58.0	69.6
1.3	59.9	77.9	59.7	77.6	60.7	78.9
1.4	62.0	86.8	62.5	87.5	63.3	88.6
1.5	64.7	97.1	65.1	97.7	65.8	98.7
1.6	67.3	107.7	67.6	108.2	68.0	108.8
1.7	69.8	118.7	70.0	118.9	70.2	119.3
1.8	72.2	129.9	72.2	130.0	72.2	130.0
1.9	74.4	141.4	74.3	141.2	74.1	140.8
2.0	76.6	153.2	76.4	152.7	76.0	152.0
2.1	78.7	165.2	78.3	164.14	77.7	163.2
2.2	80.6	177.4	80.1	176.13	79.3	174.5
2.3	82.5	189.8	81.9	188.4	80.9	186.1
2.4	84.3	202.4	83.6	200.10	82.4	197.8

TABLE 3.

Based on Kutter's formulæ with $n = .025$.

Values of the factors c and $c\sqrt{r}$ for use in the formulæ:—

$$V = c\sqrt{rs} = c \times \sqrt{r} \times \sqrt{s} = c\sqrt{r} \times \sqrt{s}$$

$\sqrt{r}$ in feet.	1 in 7500		1 in 5000		1 in 3333.3	
	0.704 feet per mile.		1.056 feet per mile.		1.584 feet per mile.	
	$s = .000133333$		$s = .0002$		$s = .0003$	
	c	$c\sqrt{r}$	c	$c\sqrt{r}$	c	$c\sqrt{r}$
.4	27.5	11.0	28.6	11.4	29.5	11.8
.5	33.7	16.4	33.9	17.0	34.8	17.4
.6	37.4	22.4	38.6	23.2	39.5	23.7
.7	41.6	29.1	42.9	30.0	43.8	30.7
.8	45.6	36.5	46.8	37.4	47.6	38.1
.9	49.2	44.3	50.3	45.3	51.1	46.0
1.0	52.6	52.6	53.6	53.6	54.3	54.3
1.1	55.7	61.3	56.6	62.3	57.2	62.9
1.2	58.5	70.2	59.3	71.2	59.9	71.9
1.3	61.2	79.6	61.9	80.5	62.3	81.0
1.4	63.7	89.2	64.3	90.0	64.6	90.4
1.5	66.1	99.2	66.5	99.8	66.7	100.1
1.6	68.2	109.1	68.5	109.6	68.7	109.9
1.7	70.3	119.5	70.4	119.7	70.5	119.9
1.8	72.2	130.0	72.3	130.1	72.3	130.1
1.9	74.1	140.8	73.9	140.4	73.9	140.4
2.0	75.8	151.6	75.6	151.2	75.4	150.8
2.1	77.4	162.5	77.1	161.9	76.8	161.3
2.2	79.0	173.8	78.5	172.7	78.1	171.8
2.3	80.4	184.9	79.8	183.5	79.4	182.6
2.4	81.8	196.3	81.1	194.6	80.6	193.4

TABLE 3.

Based on Kutter's formulæ with $n = .025$.

Values of the factors c and $c\sqrt{r}$ for use in the formulæ:—

$$V = c\sqrt{rs} = c \times \sqrt{r} \times \sqrt{s} = c\sqrt{r} \times \sqrt{s}$$

$\sqrt{r}$ in feet.	1 in 2500		1 in 1666.7		1 in 1000	
	2.112 feet per mile.		3.168 feet per mile.		5.28feet per mile.	
	$s = .0004$		$s = .0006$		$s = .001$	
	c	$c\sqrt{r}$	c	$c\sqrt{r}$	c	$c\sqrt{r}$
.4	30.0	12.0	30.5	12.2	30.9	12.4
.5	35.3	17.7	35.8	17.9	36.3	18.2
.6	40.0	24.0	40.5	24.3	41.0	24.6
.7	44.2	30.9	44.7	31.3	45.2	31.6
.8	48.0	38.4	48.5	38.8	48.9	39.1
.9	51.5	46.4	51.9	46.7	52.3	47.1
1.0	54.6	54.6	55.0	55.0	55.4	55.4
1.1	57.5	63.3	57.9	63.7	58.2	64.0
1.2	60.1	72.1	60.4	72.5	60.7	72.8
1.3	62.6	81.4	62.8	81.6	63.0	81.9
1.4	64.8	90.7	65.0	91.0	65.2	91.3
1.5	66.9	100.4	67.0	100.5	67.2	100.8
1.6	68.8	110.1	68.9	110.2	69.0	110.4
1.7	70.6	120.0	70.6	120.0	70.7	120.2
1.8	72.3	130.1	72.3	130.1	72.3	130.1
1.9	73.8	140.2	73.8	140.2	73.8	140.2
2.0	75.3	150.6	75.2	150.4	75.1	150.2
2.1	76.7	161.1	76.5	160.7	76.4	160.4
2.2	78.0	171.6	77.8	171.2	77.7	170.9
2.3	79.2	182.2	79.0	181.7	78.8	181.2
2.4	80.4	193.0	80.1	192.2	79.9	191.8

TABLE 4.

Based on Kutter's formulæ with $n = .0275$.

Values of the factors c and $c\sqrt{r}$ for use in the formulæ:—

$$V = c\sqrt{rs} = c \times \sqrt{r} \times \sqrt{s} = c\sqrt{r} \times \sqrt{s}$$

$\sqrt{r}$ in feet	1 in 20000		1 in 15840		1 in 10000	
	0.264 feet per mile.		0.3333 feet per mile.		0.528 feet per mile.	
	$s = .00005$		$s = .000063131$		$s = .0001$	
	c	$c\sqrt{r}$	c	$c\sqrt{r}$	c	$c\sqrt{r}$
.4	21.2	8.5	22.0	8.8	23.4	9.4
.5	25.6	12.8	26.5	13.2	28.0	14.0
.6	29.8	17.9	30.7	18.4	32.3	19.4
.7	33.8	23.7	34.7	24.3	36.3	25.4
.8	37.5	30.0	38.4	30.7	39.9	31.9
.9	41.0	36.9	41.9	37.7	43.3	39.0
1.0	44.4	44.4	45.1	45.1	46.5	46.5
1.1	47.5	52.2	48.2	53.0	49.4	54.4
1.2	51.1	61.4	51.1	61.3	52.2	62.6
1.3	53.3	69.3	53.9	70.0	54.8	71.2
1.4	56.0	78.4	56.5	79.0	57.2	80.1
1.5	58.6	87.9	58.9	88.4	59.5	89.3
1.6	61.0	97.7	61.3	98.0	61.7	98.7
1.7	63.4	107.8	63.5	108.0	63.7	108.3
1.8	65.6	118.3	65.6	118.1	65.6	118.2
1.9	67.8	128.7	67.6	128.5	67.5	128.2
2.0	69.8	139.6	69.1	138.1	69.2	138.4
2.1	71.7	150.7	71.4	150.0	70.9	148.8
2.2	73.6	162.0	73.2	161.0	72.4	159.4
2.3	75.4	173.5	74.9	172.2	73.9	170.1
2.4	77.2	185.2	76.5	183.6	75.4	180.9

TABLE 4.

Based on Kutter's formulæ with $n = .0275$.

Values of the factors c and $c\sqrt{r}$ for use in the formulæ:—

$$V = c\sqrt{rs} = c \times \sqrt{r} \times \sqrt{s} = c\sqrt{r} \times \sqrt{s}$$

$\sqrt{r}$ in feet.	1 in 7500		1 in 5000		1 in 3333.3	
	0.704 feet per mile.		1.056 feet per mile.		1.584 feet per mile.	
	$s = .000133333$		$s = .0002$		$s = .0003$	
	c	$c\sqrt{r}$	c	$c\sqrt{r}$	c	$c\sqrt{r}$
.4	24.2	9.7	25.2	10.1	25.9	10.4
.5	28.9	14.4	29.9	15.0	30.7	15.4
.6	33.2	19.9	34.2	20.5	35.0	21.0
.7	37.1	26.0	38.1	26.7	38.9	27.2
.8	40.7	32.6	41.7	33.4	42.4	33.9
.9	44.1	39.7	45.0	40.5	45.7	41.1
1.0	47.2	47.2	48.0	48.0	48.6	48.6
1.1	50.1	55.1	50.8	55.9	51.4	56.5
1.2	52.7	63.3	53.4	64.1	53.9	64.7
1.3	55.2	71.8	55.8	72.5	56.2	73.1
1.4	57.6	80.6	58.5	81.9	58.4	81.7
1.5	59.8	89.7	60.1	90.2	60.4	90.6
1.6	61.9	99.0	62.1	99.4	62.3	99.6
1.7	63.3	107.6	63.9	108.7	64.0	108.8
1.8	65.7	118.2	65.7	118.2	65.7	118.2
1.9	67.4	128.0	67.3	127.9	67.2	127.7
2.0	69.0	138.1	68.8	137.7	68.7	137.4
2.1	70.6	148.2	70.3	147.6	70.1	147.1
2.2	72.1	158.5	71.6	157.6	71.4	157.0
2.3	73.5	169.0	72.9	167.8	72.6	166.9
2.4	74.8	179.5	74.2	178.1	73.7	177.0

TABLE 4.

Based on Kutter's formulæ with $n = .0275$.

Values of the factors c and $c\sqrt{r}$ for use in the formulæ:—

$$V = c\sqrt{rs} = c \times \sqrt{r} \times \sqrt{s} = c\sqrt{r} \times \sqrt{s}$$

$\sqrt{r}$ in feet.	1 in 2500		1 in 1666.7		1 in 1000	
	2.114 feet per mile.		3.168 feet per mile.		5.28 feet per mile.	
	$s = .0004$		$s = .0006$		$s = .001$	
	c	$c\sqrt{r}$	c	$c\sqrt{r}$	c	$c\sqrt{r}$
.4	26.4	10.5	26.8	10.7	27.2	10.9
.5	31.2	15.6	31.6	15.8	32.0	16.0
.6	35.5	21.3	35.9	21.5	36.3	21.8
.7	39.3	27.5	39.8	27.8	40.2	28.1
.8	42.8	34.3	43.3	34.6	43.6	34.9
.9	46.0	41.4	46.4	41.8	46.8	42.1
1.0	49.0	49.0	49.3	49.3	49.6	49.6
1.1	51.7	56.8	52.0	57.2	52.3	57.5
1.2	54.1	64.9	54.4	65.3	54.6	65.6
1.3	56.4	73.4	56.7	73.7	56.9	73.9
1.4	58.5	82.0	58.7	82.2	58.9	82.4
1.5	60.5	90.8	60.7	91.0	60.8	91.2
1.6	62.4	99.8	62.5	99.9	62.5	100.1
1.7	64.1	108.9	64.1	109.0	64.2	109.1
1.8	65.7	118.2	65.7	118.2	65.7	118.2
1.9	67.2	126.7	67.2	127.6	67.1	127.5
2.0	68 6	137.2	68.5	137.0	68.5	136.9
2.1	69.9	146.9	69.8	146.6	69.7	146.4
2.2	71.7	156.5	71.0	156.3	70.9	156.0
2.3	72.4	166.5	72.2	166.0	72.0	165.6
2.4	73.6	176.5	73.3	175.9	73.1	175 4

TABLE 5.

Based on Kutter's formulæ with $n = .03$.

Values of the factors c and $c\sqrt{r}$ for use in the formulæ:—

$$V = c\sqrt{rs} = c \times \sqrt{r} \times \sqrt{s} = c\sqrt{r} \times \sqrt{s}$$

$\sqrt{r}$ in feet.	1 in 20000		1 in 15840		1 in 10000	
	0.264 feet per mile.		0.3333 feet per mile.		0.528 feet per mile.	
	$s = .00005$		$s = .000063131$		$s = .0001$	
	c	$c\sqrt{r}$	c	$c\sqrt{r}$	c	$c\sqrt{r}$
.4	19.0	7.59	19.6	7.86	20.9	8.4
.5	23.0	11.5	23.8	11.9	25.1	12.6
.6	26.9	16.1	27.6	16.6	29.0	17.4
.7	30.5	21.3	31.2	21.9	32.6	22.8
.8	33.9	27.1	34.6	27.7	36.0	28.8
.9	37.1	33.4	37.9	34.1	39.1	35.2
1.0	40.2	40.2	40.9	40.9	42.1	42.1
1.1	43.1	47.4	43.7	48.1	44.8	49.3
1.2	45.9	55.1	46.5	55.8	47.4	56.9
1.3	48.6	63.1	49.0	63.8	49.9	64.9
1.4	51.1	71.5	51.4	72.0	52.2	73.1
1.5	53.5	80.3	53.8	80.7	54.3	81.5
1.6	55.8	89.3	56.0	89.6	56.4	90.2
1.7	58.0	98.6	58.1	98.8	58.3	99.1
1.8	60.1	108.2	60.2	108.3	60.2	108.4
1.9	62.2	118.1	62.1	117.9	61.9	117.6
2.0	64.1	128.2	63.9	127.8	63.6	127.2
2.1	66.0	138.5	65.7	137.9	65.2	136.9
2.2	67.8	149.1	67.4	148.2	66.7	146.7
2.3	69.5	159.9	69.0	158.7	68.1	156.6
2.4	71.2	170.8	70.5	169.3	69.5	166.8

TABLE 5.

Based on Kutter's formulæ with $n = .03$

Values of the factors c and $c\sqrt{r}$ for use in the formulæ:—

$$V = c\sqrt{rs} = c \times \sqrt{r} \times \sqrt{s} = c\sqrt{r} \times \sqrt{s}$$

$\sqrt{r}$ in feet.	1 in 75000		1 in 5000		1 in 3333.3	
	0.528 feet per mile.		1.056 feet per mile.		1.584 feet per mile.	
	$s = .000133333$		$s = .0002$		$s = .0003$	
	c	$c\sqrt{r}$	c	$c\sqrt{r}$	c	$c\sqrt{r}$
.4	21.5	8.6	22.4	8.96	23.1	9.24
.5	25.8	12.9	26.7	13.4	27.4	13.7
.6	29.7	17.8	30.7	18.4	31.4	18.8
.7	33.3	23.3	34.3	24.0	35.0	24.5
.8	36.7	29.4	37.6	30.1	38.2	30.6
.9	39.8	35.8	40.6	36.5	41.2	37.1
1.0	42.7	42.7	43.5	43.5	44.0	44.0
1.1	45.4	49.9	46.1	50.7	46.6	51.3
1.2	47.9	57.5	48.5	58.2	49.0	58.8
1.3	50.3	65.4	50.8	66.0	51.2	66.6
1.4	52.5	73.5	52.9	74.1	53.2	74.5
1.5	54.6	81.9	54.9	82.4	55.1	82.7
1.6	56.5	90.4	56.8	90.9	56.9	91.0
1.7	58.4	99.3	58.5	99.5	58.6	99.6
1.8	60.2	108.4	60.2	108.4	60.2	108.4
1.9	61.9	117.6	61.8	117.4	61.7	117.2
2.0	63.4	126.8	63.2	126.4	63.1	126.2
2.1	64.9	136.3	64.6	135.7	64.4	135.2
2.2	66.4	146.1	66.0	145.2	65.7	144.5
2.3	67.7	155.7	67.2	154.6	66.9	153.9
2.4	69.0	165.6	68.4	164.2	68.0	163.2

TABLE 5.

Based on Kutter's formulæ with $n = .03$.

Values of the factors c and $c\sqrt{r}$ for use in the formulæ:—

$$V = c\sqrt{rs} = c \times \sqrt{r} \times \sqrt{s} = c\sqrt{r} \times \sqrt{s}$$

$\sqrt{r}$ in feet.	1 in 2500		1 in 1666.7		1 in 1000	
	2.114 feet per mile.		3.168 feet per mile.		5.28 feet per mile.	
	$s = .0004$		$s = .0006$		$s = .001$	
	c	$c\sqrt{r}$	c	$c\sqrt{r}$	c	$c\sqrt{r}$
.4	23.5	9.4	23.9	9.6	24.2	9.7
.5	27.8	13.9	28.2	14.1	28.6	14.3
.6	31.8	19.1	32.2	19.3	32.5	19.5
.7	35.3	24.7	35.8	25.1	36.1	25.3
.8	38.6	30.9	39.0	31.2	39.3	31.4
.9	41.6	37.4	41.9	37.7	49.2	38.0
1.0	44.3	44.3	44.7	44.7	44.9	44.9
1.1	46.8	51.5	47.1	51.8	47.4	52.1
1.2	49.2	59.0	49.4	59.3	49.7	59.6
1.3	51.4	66.8	51.6	67.1	51.8	67.3
1.4	53.4	74.8	53.5	74.9	53.7	75.2
1.5	55.2	82.8	54.4	81.6	55.5	83.3
1.6	57.0	91.2	57.1	91.4	57.2	91.5
1.7	58.7	99.8	58.7	99.8	58.7	99.8
1.8	60.2	108.4	60.2	108.4	60.2	108.4
1.9	61.6	117.0	61.6	117.0	61.6	117.0
2.0	63.0	126.0	62.9	125.8	62.9	125.8
2.1	64.5	135.0	64.2	134.8	64.1	134.6
2.2	65.5	144.1	65.4	143.9	65.3	143.7
2.3	66.7	153.4	66.5	153.0	66.3	152.5
2.4	67.8	162.7	67.6	162.4	67.4	161.8

TABLE 6. SLOPES.

Giving the fall in inches per mile; the distance corresponding to a fall of one, and also the values of s and $\sqrt{s}$

$s = \frac{h}{l}$ = sine of slope = fall of water surface (h) in any distance (l) divided by that distance:—

Fall in inches per mile.	Slope 1 in.	s	$\sqrt{s}$
2	31680	.000031565	.005618
2½	25344	.000039457	.006281
3	21120	.000047349	.006881
3½	18103	.000055240	.007432
4	15840	.000063131	.007945
4½	14080	.000071023	.008427
5	12672	.000078913	.008883
5½	11520	.000086805	.009317
6	10650	.000094697	.009731
6½	9748	.000102588	.010129
7	9051	.000110479	.010511
7½	8448	.000118371	.010880
8	7920	.000126261	.011237
8½	7454	.000134154	.011583
9	7040	.000142045	.011918
9½	6670	.000149937	.012245
10	6336	.000157828	.012563
10½	6034	.000165720	.012873
11	5760	.000173598	.013176
11½	5510	.000181502	.013472
12	5280	.000189393	.013762

TABLE 6. SLOPES.

Fall in inches per mile.	Slope 1 in.	s	$\sqrt{s}$
12½	5069	.000197285	.014016
13	4874	.000205182	.014324
13½	4693	.000213068	.014597
14	4526	.000220960	.014865
14½	4370	.000228851	.015128
15	4224	.000236742	.015386
15½	4088	.000244634	.015641
16	3960	.000252525	.015891
16½	3840	.000260411	.016137
17	3727	.000268308	.016381
17½	3621	.000276199	.016619
18	3520	.000284091	.016854
18½	3425	.000291982	.017087
19	3335	.000299874	.017317
19½	3249	.000307765	.017543
20	3168	.000315656	.017767
20½	3091	.000323548	.017987
21	3017	.000331439	.018205
21½	2947	.000339331	.018421
22	2880	.000347222	.018634
22½	2816	.000355114	.018844
23	2755	.000363005	.019052
23½	2696	.000370896	.019259
24	2640	.000378787	.019463

TABLE 6. SLOPES.

Fall in feet per mile.	Slope 1 in.	s	$\sqrt{s}$
3	1760	.000568182	.023836
4	1320	.000757576	.027524
5	1056	.000946969	.030773
6	880.0	.001136364	.033710
7	754.3	.001325797	.036411
8	660.0	.001515151	.038925
9	586.6	.001704545	.041286
10	528.0	.001893939	.043519
11	443.6	.002083333	.045643
12	440.0	.002272727	.047673
13	406.1	.002462121	.049620
14	377.1	.002651515	.051493
15	352.0	.002840909	.053300
16	330.0	.003030303	.055048
17	310.6	.003219696	.056742
18	293.3	.003409090	.058388
19	277.9	.003598484	.059988
20	264.0	.003787878	.061546
21	251.4	.003977272	.063066
22	240.0	.004166667	.064549
23	229.6	.004356060	.066000
24	220.0	.004545454	.067419
25	211.2	.004734848	.068810
26	203.1	.004924242	.070173
27	195.2	.005113636	.071510
28	188.6	.005303030	.072822
29	182.1	.005492424	.074111
30	176.0	.005681818	.075378
31	170.3	.005871219	.076624
32	165.0	.006060606	.077850
33	160.0	.006250000	.079057

KUTTER'S FORMULA.

By P. J. Flynn, C. E., Mem. Tech. Soc.

In January, 1886, a paper on a modification of Kutter's formula, as given in the twenty-first edition of Molesworth's Engineering Pocket Book, appeared in the Transactions of the Technical Society of the Pacific Coast.

In Van Nostrand's Engineering Magazine for September, 1886, is a letter on this subject from Mr. Guildford Molesworth, the author of the Pocket Book, of which the following is a copy:

To the Editor of Van Nostrand's Magazine:

Mr. Flynn' criticism of my modification of Kutter's formula for pipes has just reached me. Mr. Flynn is quite correct. The formula as it stands in page 25 of the twenty-first edition of my pocket book has an omission of $\sqrt{d}$. As I originally framed it, it stood thus:

$$C = \frac{181 + \frac{.00281}{s}}{1 + \frac{.026}{\sqrt{d}}\left(41.6 + \frac{.00281}{s}\right)}$$

Unfortunately the omission of $\sqrt{d}$ escaped my observation in correcting the proofs of this twenty-first edition.

Taking the side cases which Mr. Flynn has worked out, a comparison of Kutter's formula and my modification of it for pipes, as corrected, stands thus:

Diameter of Pipe.	Slope 1 inch.	Kutter.	Molesworth.
6 inches	40	71.50	71.48
6 inches	1000	69.50	69.79
4 feet	400	117.00	117.00
4 feet	1000	116.5	116.55
8 feet	700	130.5	130.68
8 feet	2600	129.8	129.93

The two formulæ are thus far substantially identical in results though differing slightly in form.

Guildford Molesworth.

Simla, India, May 17, 1886.

TECHNICAL SOCIETY OF THE PACIFIC COAST.

SAN FRANCISCO, CALIFORNIA.

INSTITUTED APRIL, 1884.

PROCEEDINGS.

(VOLUME VII.—No. 3.)

MINUTES OF MEETINGS.

REGULAR MEETING.

May 2, 1890.

Called to order at 8:30 P. M. by President Richards.

The minutes of the last regular meeting were read and approved.

After a count of ballots the following gentlemen were declared elected members of the Society: Messrs. Adolph Lietz, William M. Fitzhugh and Joseph A. Sladky.

The following propositions were read and disposed of in the usual way:

For members—Frank Pettit, mechanical engineer, proposed by H. C. Behr, Otto v. Geldern and Geo. F. Schild; W. B. Storey, Jr., civil engineer, proposed by L. Tasheira, L. M. Clement and H. D. Gates; P. M. Norboe, civil engineer, Visalia, Cal., proposed by P. J. Flynn, Burr Bassell and Otto v. Geldern.

For associate—Thomas Hamlin, attorney-at-law, proposed by Otto v. Geldern, Geo. F. Schild and L. Wagoner.

The American Society of Civil Engineers donated all past transactions prior to 1884, which have been received by the Secretary and sent to the bookbinder. The announcement of this very acceptable gift was received with applause.

A communication was read from C. L. Stevenson, Esq., hydraulic engineer, of Salt Lake City, announcing the organization of a Polytechnic Society of Utah, composed of the prominent engineers and technologists of that part of the territory. Communication placed on file.

Mr. P. M. Randall, civil engineer, then read a very exhaustive mathematical treatment, prepared with great care and labor, on the principle of the Air Lift-Pump of Dr. Pohlé. After the reading of the paper questions were asked and answered as to the practical utility of the apparatus, and references made to a communication on the subject from Mr. Hawgood, a member of the Institution of Civil Engineers, which was taken up by Mr. Randall in a special paper containing his views on that particular point. Another paper on the principle of the pump, by Mr. Luther Wagoner, was read by title only and referred to the Executive Committee, together with all the subject matter and discussion thus far on hand, preparatory to publication.*

A communication from the American Society of Civil Engineers was read, being a report of a Committee on Revision of the Constitution, signed by Chairman Shinn. This communication requests that the views of the different Engineering Societies of the country be submitted on the subject of a closer intercommunication and fraternization in their relation to each other. After consideration it was thought necessary to take immediate action, and it was moved to refer the matter to the Executive Committee, with instructions to advise the Secretary as to the reply. Carried.

The Executive Committee not being complete, by reason of Mr. Hubert Vischer's absence, the President appointed Mr. Luther Wagoner to act temporarily as member thereof.

The Secretary having requested to be represented during an absence of several weeks, the Chair appointed Mr. Geo. F. Schild to act until the return of Mr. Otto von Geldern.

President Richards called attention to two concrete bricks submitted by the manufacturer, Mr. Chas. Turrell. The maker explained that they were made of blue rock (taken from the vicinity of Second-Street cut) and Portland cement. The rock is pulverized, mixed with the cement and submitted to a pressure of 50 tons to a brick of the ordinary size. There is no burning in their manufacture. The percentage of the cement varies with the material used. Their strength is very great, and if laid in cement they form a perfect concrete wall. The

* The publication of this entire subject has been postponed for the present.

absorbing power is small, and the specific gravity about 1.9. It was stated that they could be made to compete with the ordinary burned brick. Mr. Manson asked if he could procure about one thousand of these bricks to test them in his water-front work, to which the manufacturer readily agreed.

Mr. B. McIntyre, a mechanical engineer, being asked if he would present the Society with a paper on Wire-Rope Transmission, promised to do so at an early date.

Meeting adjourned.

OTTO VON GELDERN,
Secretary.

REGULAR MEETING.

June 6, 1890.

Called to order at 8:30 P. M. by the Vice-President, Professor Frank Soulé.

The minutes of the last regular meeting were read and approved.

The Secretary having reported the donation of twenty-seven numbers of the "U. S. Naval Institute," and from the President, Mr. John Richards, files of the "London Engineer," "Engineering," "Industry," and "Iron Age," it was ordered that the receipt be acknowledged and that the donors be thanked for their valuable gifts.

Professor Irving Stringham, of the University of California, then delivered a very able paper entitled, "Napier's Definition of a Logarithm and its Consequences," which claimed the attention of the Society and led to a lengthy discussion subsequently.

A vote of thanks for Professor Stringham was passed.

The Pacific Electrical Storage Company of San Francisco, having extended an invitation to this Society to call upon the firm and inspect the large lighting plant now in operation, Mr. N. S. Keith moved:

That the thanks of the Society be communicated to the Pacific Electrical Storage Company for the invitation; that the Secretary arrange a time for the proposed visit, and notify the members in accordance therewith; that the Company be invited to

exhibit and explain its apparatus before the Society at a meeting which shall be arranged and called by the President and Secretary. Carried.

The following letter was read, which is to be forwarded as a reply of the Executive Committee of this Society to the American Society of Civil Engineers, in the matter of suggesting a plan for effecting a closer intercommunication and fraternization of the various Technical Societies in the United States:

San Francisco, June 6, 1890.

Mr. John Bogart,

Secretary American Society of Civil Engineers, New York:

Dear Sir—At the regular meeting of this Society, May 2d, your communication concerning some enlarged action by the various Societies of the land, was read and referred to the Executive Committee, with power to act, and I herewith transmit a copy of its report:

"The Executive Committee greatly regrets that the communication was not received in time for general discussion by the Society.

"Personally we doubt the advisability of the absorption of the smaller Societies by a general Society. However, we should greatly favor a suitable plan for the distribution of the printed papers of each Society among the members of all Engineering and Technical Societies co-operating for such purpose; also, an understanding among such Societies leading to a free exchange of communications and discussions.

(Signed) S. Harrison Smith,
H. C. Behr,
Luther Wagoner,
Ex. Com. Tech. Soc."

I am, very respectfully,

Geo. F. Schild, Acting Secretary.

Upon a count of ballots the following gentlemen were declared duly elected:

Members—Frank Pettit, mechanical engineer; W. B. Storey, Jr., civil engineer, Visalia, Cal.; P. M. Norboe, civil engineer.

Associate—Thomas Hamlin, attorney-at-law.

C. D. Harvey, of Harvey & Graves, San Francisco, having

been invited to exhibit his new water and steam pipe couplings, explained this invention by diagrams and models, claiming that he had overcome, to a great extent, the resistance to the currents in the old-style elbows and T's, which was due to the lodgment of air and rough projections. His new reducer and T-reducer especially attracted the attention of the members. Pipes of different sizes are thereby brought to the same level on the upper edge, obviating any air-chambers. The inside of all his fittings are equal to the inside diameter of the connecting pipes, and as fittings and pipes join closely he obtains an even and smooth passage and avoids friction.

A number of questions were asked by the members regarding the cost, etc., and the tightness of his new fittings, which the inventor answered.

Meeting adjourned.

GEO. F. SCHILD,
Acting Secretary.

REGULAR MEETING.

JULY 9, 1890.

On account of the holiday on Friday, July 4th, the regular meeting of the Society was held on Wednesday, July 9th.

Called to order at 8:30 P. M., President John Richards in the Chair.

The minutes of the last regular meeting were read and approved.

Mr. Jason R. Meek, County Surveyor of Yuba County, was proposed for membership by Otto von Geldern, Geo. F. Schild and H. C. Behr.

The following donations were announced by the Secretary:

"Annales des Ponts et Chaussees," 1890, in four parts.

"Mittheilungen des Deutsch-Amerikanischen Techniker Verbandes," New York 1885 to 1890.

"Ninth Annual Report of the State Mineralogist of California," 1890, by Wm. Irelan, Jr., State Mineralogist.

"Proceedings of the American Institute of Mining Engineers," containing a list of officers and members and the trans-

actions of the Ottawa meeting, October, 1889, and the Washington meeting, February, 1890.

"A Bibliography of Geodesy," by J. Howard Gore, B. S. Ph.D., published by the U. S. Coast and Geodetic Survey.

A communication was read from the Western Society of Engineers, of Chicago, Ill., inviting this Society to appoint a committee to meet similar committees from kindred Societies at the rooms of the Western Society of Engineers, No. 78 La Salle street, Chicago, on Tuesday, October 14, 1890, for the purpose of formulating a plan for holding an International Engineering Congress during the World's Columbian Exposition, to be held at Chicago in 1893. Engineering Societies in this and other countries are to be asked to send delegates to this Congress, and Governments themselves requested to send representatives.

The Secretary was instructed to reply to this letter, expressing the inability of this Society to send a committee, in such terms of regret as he should deem proper.

The following communication was read from the American Society of Civil Engineers:

"New York, June 9, 1890.

To Otto von Geldern,

Secretary Technical Society of the Pacific Coast:

Dear Sir—The Board of Direction of the American Society of Civil Engineers invites the officers of your Society to attend the Annual Convention of this Society, at Cresson, Pa., beginning June 26, 1890. Circulars of information are sent you to-day, which kindly distribute among your officers.

For the Board of Direction,

(Signed) John Bogart,

Sec. Am. Soc. C. E."

The Secretary announced that he had distributed the invitation cards, and had acknowledged the letter in suitable form.

A communication was read from the Pacific Electrical Storage Company, stating that this Company had accepted the invitation of the Technical Society to make an exhibition and explain the science and action of electrical accumulators or storage batteries before the Society at one of its meetings. It was requested

that the Society make the arrangements and set the date for such an exhibition, and inform the Company at an early date, so that the electrician, Mr. R. B. Elder, may have time to prepare a paper and the necessary apparatus for the occasion.

The Secretary stated that the understanding had been between the Company and the Society that the time best suited would be Friday, August 1, 1890, and that Mr. R. B. Elder had been notified of the date and had agreed to the arrangement.

A paper was presented before the Society by Mr. P. J. Flynn, C. E., a member, the title and general contents of which were made known to the members. It treats of the subject of the "Flow of Water in Open Channels," and contains practical tables deduced from accepted formulæ.

Mr. B. McIntyre, mechanical engineer, then read a very interesting paper on "Ropeway Transmission," in which he set forth his experiences in constructing a ropeway 10,116 feet long for the Plomosas Mining Company in Sinaloa, Mexico.*

The paper was listened to with great interest, and its practical value freely acknowledged. In conclusion, the author was given a vote of thanks by the Society.

The President appointed Mr. H. C. Behr a member of the Board of Directors to act in the absence of Mr. Hubert Vischer.

Meeting adjourned.

OTTO VON GELDERN,
Secretary.

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*This paper will be published in the next issue,

TECHNICAL SOCIETY OF THE PACIFIC COAST.

SAN FRANCISCO, CALIFORNIA.

INSTITUTED APRIL, 1884.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the statements and opinions advanced in any of its publications.

(VOLUME VII. No. 4.)

A FEW FACTS ABOUT WIRE ROPEWAYS, WITH NOTES ON THE PLOMOSOS LINE.

BY B. MCINTIRE, MEM. TECH. SOC.

Read July 9, 1890.

The system of transporting material by means of the "Wire Ropeway," or endless traveling wire rope, has been thoroughly tested during the past eighteen years; the results proving that a well-constructed ropeway, with the latest improvements, is as sure in its operation as is a railway. It has proved to be cheap in first cost and construction, reliable in operation (not being affected by changes in weather), and most economical in operating expenses and repairs.

Ropeways have been used for transporting many kinds of material, such as ore, cord wood, rails, lumber, sugar cane, produce, etc.

As is well known, there are on the Pacific Coast many valuable mining properties undeveloped on account of the ore being of too low grade to be worked profitably by the usual method of erecting steam power reduction works at the mines. By grinding these ores in a mill driven by water power, which in many cases may be found within a few miles distance, these may often become valuable properties. The question of transportation is in many cases the only difficulty, and a well constructed wire ropeway will often be found to solve the problem.

The construction is the following: An endless wire rope, at intervals of from 140 to 2,000 feet, is supported on suitable sheaves, which are mounted vertically on the ends of cross-arms fixed to the necessary posts or supporting structures, and at a sufficient height to clear all surface obstructions. At both ends of the line, the wire rope passes around sheaves set horizontally. These sheaves are either grip or plane sheaves, as the case may require. Grip sheaves are used where power is to be supplied to the rope, or to prevent slipping where brakes are used to regulate the speed, the brake wheel being then attached to the upper side of the grip pulley.

Buckets or carriers of various designs, differing according to the character of the material to be handled, are used. These are suspended by hangers and clips, which are either inserted into the rope or strapped around the outside of it, and are attached at intervals determined by the amount of material to be delivered, calculating the rope to run at a speed of about 200 feet per minute. The clips are so made that they may pass over the rims of the carrying sheaves and around the horizontal terminal sheaves. The carriers may be loaded at any part of the road, either by the use of an automatic loader or by hand labor, while at the point of discharge the carriers unload automatically, the rope not being stopped either to load or unload.

When the point of delivery is lower than the loading point, and the inclination greater than about one in seven, the ropeway will run by gravitation, the speed being regulated by a brake; when less than one in seven, auxiliary power must be employed. A ropeway, running 200 feet per minute, with ore buckets attached at intervals of 48 feet, carrying 160 lbs. per bucket, will deliver 20 tons per hour. If run by gravity, with a loading device and one man to look after it, one man at the brake and one man at the discharge end; three men can deliver 200 tons of ore, at a cost of about three cents per ton for labor. By using two clips close together on the rope, loads of 500 to 700 lbs. per bucket or carrier can be transported.

NOTES ON THE PLOMOSAS ROPEWAY.

In the year 1884 the author was called upon to construct and put in operation a ropeway for the Plomosas Mining Company,

State of Sinaloa, Mexico. A record of the construction, together with a statement of the difficulties which had to be overcome may not prove uninteresting from one familiar with this class of work, and may perhaps be valuable to other engineers who may have occasion to plan a similar plant. Before entering upon this work I had constructed a ropeway 4,400 feet long for Mr. E. Wertherman, at Topia, State of Durango, Mexico (it being, by the bye, the first ropeway built in Mexico). Upon assuming duty as their engineer, my recommendation to the Plomosas Company was to construct a ropeway, on account of the high and yearly increasing cost of fuel, and as a means of reducing their yearly debt; for the property, although valuable, was not profitable as then operated.

After having located the best wooded part of the table land, two miles from the mill, a site for the upper terminal was selected in a position which gave the straightest line, together with the shortest spans, and in a district which would supply the mill with wood and charcoal for five years, without going outside of a half-mile radius from the terminal.

Having made the requisite survey* and obtained a profile, the first step in order, was to locate the exact position of the carrying

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* The surveys were made by telemeter measurements, which, except in cases where grade is very scant and near the limit for a gravity plant, is of quite sufficient accuracy.

It may not be uninteresting to mention that the only instrument available was a small mountain transit, which was provided with only one horizontal hair. Two extra hairs were put in, but as there were no ready means for spacing them accurately in the telescope, they were put in without reference to the distance between them, care being exercised only to make them parallel. A rod nine feet long was then placed exactly 100 feet from the instrument, and the space on the rod intersected by the hairs was measured and subdivided into tenths and hundredths. With this graduation the rest of the rod was divided off and painted; being thus empirically graduated to suit the telemeter hairs, instead of conversely, as is usually the case. The rod was used as an incline rod with guide sights for setting it at right angles to the inclination of the line of vision. Notwithstanding the extreme roughness of the ground and the makeshift nature of the stadia device, a survey was made in two and a half days, which subsequent comparison with a triangulation survey, proved to be out only 28 feet in the whole distance (two miles), and accurate to nine feet in elevation (in 3575 feet).

structures, which can be done with sufficient accuracy by tracing on the profile arcs of a parabola between the points to be selected for the supports, after having determined upon the tension and necessary sag between sustaining posts. Rules for determining the sag and tension need not be discussed here, as they can be found in any standard work on rope transmission.

The Plomosas ropeway was the first to be constructed in what may be called rough country, with a so limited number of available points for sustaining structures and such enormously long spans.

The profile, Plate 1, shows the spans, which (starting with the lower terminal) are respectively 935, 863, 104, 1378, 977, 1935, 410, 1066, 771, 833 and 433 feet; in all, 9705 feet. To this length was subsequently added 410 feet between structures 8 and 9, when the vertical turn sheaves were replaced with horizontal turn sheaves, making a total length of 10115 feet, with a difference in elevation of 3575 feet between terminals.

Construction of Terminals and Station Structures.—As a general rule, hewn timbers have to be used in ropeway construction, as sawed lumber is not available. In some cases, round poles are used. These, however, should not be employed, as they make a very poor structure, and are a continuous source of trouble and expense, taking twice as long to frame as hewn timbers, though employers are apt to think that there is economy in using the cheapest lumber that can be found, not considering the labor and subsequent expense of keeping the line in order.

In framing the terminal structures, I took great care to have the work well done, having it well bolted, and using large cast iron washers on bolts.

The upper terminal.—The upper terminal structure was made of 8 by 8 inch hewn timbers and as is shown on Plate 2.

The foundation for this terminal was made by digging a trench 45 feet long, 10 feet wide and 5 feet deep. Into this, three logs, 24 inch diameter and 40 feet long were rolled, and upon these, eight cross-ties, 24 inch diameter and 9 feet long, were placed. These were notched out on top to receive the sleepers for the track, which was 4 foot 3 inches gauge. These sleepers were bolted to the two outside bottom logs; and after everything had been well

secured with bolts, lagging was laid on top of the logs between the ties, and the spaces between were filled up with dirt. This made a very solid foundation, and the trees being cut not twenty yards away, it was the cheapest foundation that could be used.

It is not customary to have the upper terminal mounted on wheels, but at Plomosas I was restricted to 54 feet run, from the lower terminal to the counter-weight structure. In fact, no use was made of the top take-up, after it had been put in, as I had opportunities for taking up the stretch of the rope when it was cut to put in the turn sheaves, and later when the splices were renewed, as will appear further on.

Construction of intermediate structures.—In erecting the intermediate supporting structures, use was at first made of such large trees as lay in the direct line of the ropeway,* but it soon became apparent that such single post supports were of little use, although some of the trees were three feet in diameter. The vibration at these points was so great that a jerking motion was imparted to the rope whenever a clip passed over a sheave, and the latter began to cut out at the rate of $\frac{1}{8}$ inch per week where the single posts were used, although these were braced in every conceivable way, some of them having as many as twelve guy ropes run out in all directions. The supports shown on the profile at the points marked 12, 11, 10, 8 and 7, were all originally of the single post type, but they were all afterwards braced by having x-frames built around them, or were replaced by other structures when the line was straightened out and the turn put in. The supports at 6, 5, 4, 3 and 2, were originally built as trussed structures, and gave good satisfaction from the beginning. Plate 3 shows their construction, which is the best form for use in ropeways with great spans, being trussed in all directions and not being liable to get out of line, nor will the weighted

*An easy method of cutting the trees is as follows: After rigging a staging on a tree without limbs, a rope is attached as high up as possible. A cut is then made on one side, extending to the center of the trunk, after which a similar notch is made on the opposite side, about two feet higher up. After this, a couple of men at the rope can easily pull the top over, and with proper care in making the first cut, little work is needed to fit the cross-arm to its seat.

side of the rope pull the cross-arm out of level. All the bolts may become slack, and still the cross-arm will remain horizontal, which is not the case in the four-post structure commonly used, and with which, after a few days running, the unloaded side of the cross-arm will rise up, often showing a difference of eight inches in the level of the sheaves in the course of a week, and giving rise to the nuisance of keeping a man continually going over the line to tighten up bolts and get the cross-arms back into place.

In the truss structures, sills should always be used, as they prevent spreading, and keep the whole structure in line.

During three and a half years, I did not have occasion to tighten a bolt on any of the Plomosas structures.

The lower terminal.—The lower terminal structure (see Plate 2) was made of 10x10 inch timbers, with 6x8 inch timber for the track (the length of which was 65 feet), and supported on 22 inch round timbers for sleepers.

I erected a four-posted tower for a counter-weight, as shown in Sheet 4. This was 24 feet high, 10 feet square at base, and 6 feet square on top. On this two sheaves were mounted, one on top and the other at the bottom. The weight box was 5 feet square and 3 feet deep. To this a saddle carrying a 24 inch sheave was attached by four rods which passed through the bottom corners, the object being to get a double length of take-up, making 44 feet in all. This made a substantial structure and worked well, though not a structure suitable for general use, as the three bends in the rope with three sheaves are objectionally rigid and stiff. When possible, a single sheave placed at the top of a bank, or run out on an incline, is the proper way to put in a counter-weight.

At Plomosas, I let the terminal remain in one position for three or four months at a time without moving it. When the baskets got too near the ground between posts 2 and 3, or between posts 6 and 7, I would run the terminal out four or five feet, which answered quite well.

The movable terminal should have a good rail on top of the carriage wheels, to prevent its turning over should the front wheels be raised off the track, as would happen where the rope

comes to the terminal at a steep angle from a station above it. It would not be necessary where the terminal is higher than the post before it, but in all cases it is a wise precaution to have a hold-down rail, as there have been cases where, in starting a ropeway, the terminal has turned over, doing serious damage to the machinery, buckets, clips, etc.

Station structures do not need hold-down bolts, except where the rope makes a very steep angle upon leaving the sheaves, and where there is a long span in front of it, which would tend to push the frame back and overturn it. Such a condition would exist at post 7.

Transportation of Rope.—The transportation of material, when it has to be done on pack animals, becomes a very serious matter in certain classes of machinery. Transporting rope in long pieces was something new when I had the first 10,000 feet taken to Topia, in either three or four pieces (I have forgotten which), it being the first time that rope had been handled in such lengths on the Pacific Coast of Mexico, or elsewhere, I believe. The road over which the rope was carried is the roughest in the State of Durango, it taking nine days to reach Topia from Culiacan, about 110 miles, with pack animals.

The rope for Plomosas was taken in ten pieces, each piece of 2250 feet length being carried on seven mules, each carrying 321 feet with a piece ten foot long between each pair of mules, making 70 mules to the train. It required three men to take care of each seven mules.

In coiling rope for mule packing, coils should be made as small as possible, say 24 inches, for when larger it is very troublesome to fasten them to the *aparejo*, or pack saddle, which gets loose very often, causing much inconvenience when there is a long train. At present freighters will carry rope packed on ten and twelve mules at a slight advance over the regular freight rates, it having now become a common thing to carry such ropes. There are liabilities of damaging the rope by getting kinks in it, when not properly rolled and tied, or when there is too much slack left between the mules. When a rope is badly kinked, the wires of the strands on the concave side of the kink will commence to break, soon after being put into use.

At Plomosas, after the ropeway had been running four months, I had to replace two strands of the rope at points where short kinks had been made in transportation. These had been previously marked as it was suspected they would give out, as proved to be the case.*

In transporting the rope to the upper terminal, an accident occurred by which three mules were killed. The head mule at a sharp turn in the mountain trail, where a rise immediately followed a steep descent, started up the ascent with a rush until checked by the rope, which threw him backwards and over the bank, taking two other mules with him, and had the last of these not caught on a tree, the rest of the train would have followed. The path being cut out of the mountain side, and so narrow as not to admit turning a mule, or even unloading its pack, the coils which had gone over the bluff were fished up, uncoiled, and carried a quarter of a mile by hand. The rope was badly kinked through this mishap.

Distribution of Rope.—The rope used at Plomosas was 13–16 inch diameter, plough steel, of 300,000 lbs. tensile strength per square inch, and was manufactured by the California Wire Works, of this city, from special material brought from Germany.

Five of the ten pieces of rope (*i. e.* 11250 feet) were taken to the upper terminal; two pieces were left at post No. 5, two pieces placed between posts 2 and 3, and the spare one was left at the mill.

A temporary horizontal reel was constructed at the upper terminal, upon which I wound from a turn-table, three of the five pieces, splicing them together as they came. Taking eighteen men I started to draw the rope out on the right hand side of the line, not mounting it on the sheaves as I went, but drawing it along the ground. All went well until post 7 was reached (tak-

* If a short kink occurs, it may be very successfully removed by fastening two clamps to the rope, one on either side of the kink with just room between, to use a mallet freely. Then by unbending the kink in the direction in which it was formed, at the same time twisting the rope with the clamps into proper shape, and setting down with a mallet, the worst kink can be taken out, so that it cannot be noticed. Trying to pull or hammer out a kink will only make it worse, and weaken the rope more than if it were left in.

ing about three hours to distribute this portion of the rope). I had about 200 feet of the rope over the bluff, when the end lodged and ceased to run down. I was about to make the rope fast above and go down on it to loosen it below, when it suddenly freed itself and dropped, paying itself out from above with a speed that drew fire from the rocks. The man at the brake, having left it to see what was the matter below, reached the brake and stopped it just as the last line of coils was running off the drum. It would hardly be supposed that a rope laid on the ground, having to overcome the friction caused by running around stumps and over rocks, would start and run of its own accord, but it did, and when stopped, fully 1000 feet of rope lay in a heap at the bottom of the decline. This I had to turn over carefully, commencing with the first coil, until I had it all disentangled, after which the rope was drawn out without further accident, and what remained on the reel was led off back of the terminal.

The two remaining coils at the terminal were then wound on the drum, and led off on the left hand side of the line, due care being taken to avoid a repetition of accidents. When this had been accomplished, the ends at the terminal were joined, and proceeding to post 6, the rope was stretched taut with a block and tackle. With the aid of the turn-table alone, the coils between posts 5 and 6 were pulled out, a clamp device with lever attachment being used to check the rope at any moment, as it passed from the turn-table. One coil was payed out to the right and one to the left of structures. These were attached between 4 and 5, and after the upper ends had been joined to the rope above it, the line was pulled taut between 6 and 5 and 5 and 4. Then moving the turn-table to post 4, the left hand strand was run down to the mill and tightened, and then spliced to the right hand rope at that point and passed round the terminal; after which the slack between posts 2 and 3 was drawn up from above and the end made fast. The remaining gap was payed out and spliced to the right hand end between 4 and 5, which left the final splice to be put in between posts 3 and 4, which was a convenient place to make it.

The rope was next mounted on all the sheaves except 3 and 4

(on the right hand side), and with the aid of a 1½ inch Manila rope, attached to a 4 and 3-pulley block, I drew in the ends until the rope was quite taut, when attaching another block and tackle to the fall of the first block, I could with little help get it as tight as I wished.

At the end of a day, the slack was taken up, which amounted to twenty feet (due to the heat). In the first day the rope must have stretched at least 25 feet, and if the splice had been made at first, I would have lost ten feet of the counter-weight travel. The rope stretched rapidly for the first month; after that, the stretch was inconsiderable.

Having mounted the rope on post 3, I began mounting it on post 4, but not having calculated the power necessary to raise the rope on to this station, found that with a 3 and 2 sheave block, twelve men could not budge it. After procuring eight men more, and rigging a snatch block at the bottom to get a good horizontal pull, twenty men mounted it easily.

The next thing was to attach the clips, hangers and buckets, which were placed 100 feet apart. On account of the steep grades, this operation required some judgment, and was done in the following way.

Having oiled all the journals, and seen that the brakes were in good order, I attached a clamp to the rope. To this clamp was attached a 2-pulley block, having a single block placed 66 feet further out. I hitched the fall of the rope to a mule, and with the help of the men started the rope, having to change the clamp twice for each clip put on.

As the clips were attached to the rope, the baskets were loaded with the heaviest wood procurable. This was continued until the front clips reached post 8, after which, with six men the rope could be started by pulling upon it. We now discontinued loading the baskets for a while, loading them only when the men had to pull a little hard. With all care, however, it was all we could do to check the speed after the first bucket got over post 3. Having set both brakes up tight, I commenced putting on the clips every 400 feet until the first basket passed around the bottom sheaves, where they were unloaded. The baskets were next put on in rotation, and we continued to load them when neces-

sary, taking care to have them numbered, and to note which were loaded and which unloaded. After having got the first bucket back to the upper terminal without trouble, missing clips were put on as vacant spaces reached the terminal.

The rope was run three days with light loads, the buckets being only half filled. Then I commenced gradually to fill them, until I found that the two brakes would not control the speed. After running light for a week, it was decided to put on another brake on the upper terminal, for which I had already partly provided. Having a bevel gear attached to the grip sheave shaft in case of necessity, I put in a shaft with a pinion attached back through the frame. On the end of this shaft was put a heavy 36x6 inch pulley, which I had at the mill. This was fitted up with a brake band connected with levers, and sufficiently weighted to counterbalance part of the load. This worked excellently and did away with the use of the brake at the lower terminal. It also relieved, though it did not entirely overcome the rise and fall of the rope caused by having a brake on both terminals of the ropeway, the action of which is to create an accelerating motion, on account of one brake holding the rope fast while the other lets it loose.

The brakes were originally provided with hand wheels worked by screws, which is not a good device for regulating the speed. The screw is the worst form that can be used on anything like a ropeway brake, as it cannot be adjusted quickly enough. It takes so long to stop the speed, that when set the rope will almost stop before the brake can be taken off; and if eased, the rope will run away before the brake can again be set. After bothering a year with the hand-wheel brake, I connected the brake with levers, which were taken out to one side of the terminal frame at the bottom, the foot lever extending five feet out from the side of the frame. With this, the adjustment was quick, and it did away entirely with the accelerating motion of the rope, which subsequently would run for hours at a time without any rise or fall worth mentioning.

Horizontal Turn Sheaves and Alterations in Structures.—In making provision for the alignment curve, shown upon Plate 1 (see plan), I had been instructed by the manufacturer of the rope-

way to use vertical curve sheaves. The turn was made on three structures, one twelve feet in advance of post 8, another fifteen feet back of that post. The sheaves were nicely set to the line of the curve, each one taking its share of the load, which was very little, however, coming here as it did so near the natural sag of the rope. Under this arrangement, the rope on the inside of the curve, which was the loaded side, kept perpetually falling off when least expected. On the off side I put a horizontal sheave in the beginning, and that side gave no trouble. A horizontal sheave could not be used on the inside of the curve on account of the construction of the clip, which has a projecting arm or shaft attached to the rope.

The first day's run proved that the deflection curve arrangement as then constructed was not practicable, and it was decided to substitute horizontal curve sheaves, which were telegraphed for. This, however, involved a change in alignment, as the horizontal curve could not be got in on the spur of the hill upon which the turn with vertical sheaves had been made, and this change required the position of the ropeway supports to be shifted for some distance on either side of the turn. It had also become apparent that trees were not adapted as supports to such long spans, and while they may do well enough where spans are not greater than 150 or 200 feet, I should not use them again. At the end of a week it was found that while the clips were riding on the rims of the sheaves where the posts were used, there was no perceptible wear on sheaves at the trussed structures. Pending the arrival of the sheaves for putting in the horizontal turn, the following alterations were made, none of which interfered with the operation of the ropeway in the meantime:

A truss frame was set around post 12, and new structures on the trussed pattern were built to take the place of 11 and 10. These latter were set out to one side of the old posts, and were not used until the horizontal turn was put in operation.

To take the place of post 8, I made a terminal structure (see Plate 5) similar to the end terminals, and had it set 35 feet to the right of support 8, and in a direct line with the upper terminal and post 7. The horizontal 7-foot sheave, shown in the drawing,

is set to conform to the angle that the rope comes in on from post 10, as should always be done in similar cases. The structure carries an upright post, upon which is mounted the sheave to carry the rope of the unloaded side of the ropeway. This sheave is set high enough for the bottom of the basket to run clear of the turn sheave in passing over it. The superstructure is bolted to a foundation similar to that of the terminals.

At point 9, I built a similar structure (omitting the upright post and sheaves), in line with posts 7, 6, and 5, and provided two extra supports between it and post 7, in order to carry the ropeway over the intervening knoll, and to clear the buckets where the loaded rope crosses itself (see sheet 1, plan). These were made like the trussed frames shown in Plate 3, with the exception that they have an arm on one side only, having but one carrying sheave each. In place of post 7 a new structure, twenty-two feet high, was built, as shown in Plate 6, carrying two vertical sheaves on the top of the frame on the loaded side, and two vertical and one horizontal sheaves on the other side. This horizontal sheave was to make the turn on the unloaded side of the rope.

When the horizontal sheaves arrived at Plomosas, they were put in place, and 820 feet of rope spliced into the line. Great care was used in letting out rope on the new sheaves, as they appeared suspiciously light, and in fact before half the strain came upon the sheave on which I was letting out on, it broke in pieces, one section of the rim being thrown forty feet from the support. Having only a month's supply of wood at the mill, I proceeded to build two 7-foot sheaves of wood, with a hard wood seat set on ends, and got the ropeway running again in ten days. These wooden sheaves gave good satisfaction. They were used for over a year, until replaced by heavy iron sheaves made after my own design, and which were strong enough to meet the requirements.

Repairing and Splicing.—After running the ropeway two years, the splices commenced to give away at the points where the two metal strands are tucked into the rope, to take the place of the hemp heart. I commenced repairing by splicing in new strands to take the place of those worn out. After repairing six places

in this way, I concluded to renew the splices entirely. There being eleven splices to renew, I decided to put in two long pieces of rope instead of eleven short ones. The eleven short pieces would have taken 1760 feet of rope and needed twenty-two splices; the two long pieces were 520 feet each, requiring only thirteen splices.

Having marked the splices, to make them readily visible, the baskets and clips near splices were detached, and the rope-way loaded lightly. When a splice arrived near post 3 (the ground between supports 3 and 4 being easily accessible), the rope was stopped and dismounted from the sheaves at that point. The rope was then cut at the center of the old splice, and after securely fastening its lower end, the piece to be inserted was spliced to the upper end of the old rope. The lower end of the new piece was secured with block and tackle, but in a manner to allow of its being easily fed out when required.

Commencing near the upper terminal at post 12, the rope was thrown off the sheaves at points just above where a splice was to be made, and after making it securely fast so that it could not get away (using two clamps for security), enough rope to make a splice was drawn up from below, the same length being paid out from the lower end of the new piece. When the rope had been cut at the splice and a new splice made, it was re-mounted on the sheaves and the slack taken in below. The reason for keeping the rope taut all the time was to avoid dragging buckets on the ground at low places while the rope was being moved.

The order in which the splices were made was not consecutive, but so arranged as to take advantage of the ground and make splices when in the position nearest to the carrying structures. For this some latitude existed, as each splice as it was made, of course shifted the position of all the splices below it uphill, by the length required for making one splice. Even thus, some splices could not be brought closer than 200 feet from supports, in which cases difficulty was found in attaching the clamps to the rope. A rope ladder was then used to climb up to the wire of the ropeway, and this was brought to the position where it was desired to use it, by passing it over the line at the nearest

support and sliding it along the cable until in the proper position, swinging it over any intervening buckets.

After finishing one side, I let the cable make a half turn, in order to bring the other splices upon the unloaded side of the line, and then went through the same operation as before. The time and labor consumed in making the thirteen splices was nearly as much as if I had made the twenty-two splices and inserted short lengths. In the latter case, the splices could all have been made at the turn between posts 8 and 9 without much trouble, as the ropeway could have been moved after each splice was made. The reason for putting in only two long pieces of rope instead of eleven short ones, was to keep the surface of the rope as even as possible; for when a new piece of rope is spliced to an old one that is stretched and worn, the new strands will stand out somewhat from the old ones, and will wear out very rapidly. Then again, the double number of splices that would have to be put in, would become troublesome if the rope should last long enough to require renewing a second time, which I do not doubt will be the case.

It may appear strange that the wear upon the rope at splices should have been so much greater than elsewhere. A flexible wire rope (nineteen wires to the strand) can indeed be spliced so that there will be little difference in the wear, but in a rope of seven-wire strands made out of plough steel, at the points just above and below where the two steel strands are inserted into the core and take the place of the hemp heart, there is a spot (about an inch in length) where the rope has seven strands instead of six at the circumference. This makes the diameter greater, and increases the wear at the splice. Another cause of inequality is that at this point, just below where the steel strands enter the core, there is a length of say one and one-half or two inches that has no heart at all. Sometimes an outside strand will crush into this cavity, exposing the other strands to undue wear. In a flexible rope the strands can be set together with a mallet so that the splicing cannot be noticed.

Care of Cable on Ropeways.—The wire cables on ropeways need care, and like all other elements of machinery, require proper lubrication, which they seldom receive. Tar is the preservant

generally used. During a year and a half, I used Swedish tar, or a tar that was sent me under that name. This was mixed with boiled linseed oil. I had the two boiled together and the mixture distributed on the rope in the usual way, once a week. This was found an expensive and imperfect method, for the seats of the sheaves did not retain any of the tar after one day's run, and owing to the heat of the sun, I suppose, the tar hardened and baked on to the rims of the sheaves, giving no protection whatever to either rope or sheaves.

I subsequently changed the mode of application by letting the tar continuously drop on the rope, about a drop falling each minute.

This was a decided improvement over the first method of application, as the sheaves and rope retained a light coating of tar all the time, and the wear on the seats of the sheaves was reduced greatly after the continuous use of tar on the rope was commenced, while the sheaves ran four months before the tops of their rims had to be cut down, which previously had to be done every month at some points.

Tar is, however, a very poor lubricant or preserver of rope that is operated under exposure to the sun, as the heat takes up what little lubricating properties it contains.

After running the ropeway a year and a half, I had occasion to replace a damaged strand, and found that the tar had not penetrated the rope. I also noticed a good deal of wear on the wires between the strands, caused by friction in bending when passing over the sheaves. I then tried black West Virginia oil, which was put on with an automatic lubricator, using three gallons per month. At the end of four months I examined the inside of the rope again, and found it thoroughly saturated with the oil, the sheaves also showing less wear.

My expectation that the oil would preserve the Manilla core of the rope proved correct, for in renewing the splices, after using the oil six months, I found the hemp softer and more disposed to come out readily, without breaking up as much as before. The oil seemed to prevent the burning up of the core, which would in itself be a recommendation for its use; for a rope in which the core is destroyed is of little further use, as it will

wear out very rapidly on account of the unevenness of the strands. Whether due to the oil or not, the rope did not show much wear during the last two years. There was also quite a difference in the wear of the carrying sheaves, as they lasted six or seven months without the tops of the rims having to be cut off, and there was less wear of the grips on the terminal sheave.

COST OF CONSTRUCTION.

The items of Cost of Construction of the Plomosas Ropeway are as follows:

Upper Terminal:			
Timber for frame and sleepers		$ 13 75	
Cutting foundation logs		4 70	
Digging trench, setting foundation and re-splicing		68 00	
Framing and setting structures and track		85 00	
Mounting grip sheave, brake wheel and all terminal attachments		21 00	
Total			$ 192 45
Lower Terminal:			
Lumber		$112 00	
Track, framing structure, setting and mounting terminal machinery		106 00	
Total			218 00
Intermediate Structures:			
Five trees fitted for posts—Cutting tops off trees, including staging	$ 18 00		
Fitting cross-arms, bolting, mounting journals, guides, guys, etc	85 00		
		103 00	
Structure No. 6, 400 ft. lumber	276 00		
Framing	14 50		
Blasting and preparing foundation	42 00		
Hoisting to place and setting	26 00		
Getting sheaves from mill and mounting	11 00		
		369 50	
Structure No. 5, complete		287 00	
Structures Nos. 3 and 4, complete		92 00	
Special structure No. 2—Lumber, framing, excavating and mounting		105 75	

Counter Weight Tower—Timber, framing and mounting	169 00	
Remodeling structures from Post 12 to Post 6, including structures to make the turn	332 00	
Total for intermediate structures		1,458 25
Stretching, splicing and mounting rope on entire length, attaching clips and baskets		255 00
Total cost of construction		2,123 70
Ropeway material and transportation		15,454 00
Opening roads and repairing old ones		1,822 30
Total for ropeway in running order		$19,400 00

COST OF OPERATING ROPEWAY NINE MONTHS, DELIVERING 5,900 CORDS OF WOOD.

One brakeman	$468 00
Three men filling	702 00
One man dumping	354 00
One man looking after line and oiling	234 00
Oil	117 00
Repairing (which was very heavy, being $2.25 per day)	526 50
Two men employed to wheel wood away from Treminal	468 00
Two men to receive wood from choppers and deliver it to the packers	702 00
Total	$3,571 50

SUMMARY OF COMPARATIVE COSTS.

The cost at mill of 5,100 cords of wood before Ropeway was constructed was as follows:

During the year ending June, 1864, 5,100 cords of wood were consumed, costing $11.25 per cord at mill, making	$57,371 00	
Labor (handling wood at mill)	3,360 00	
Freight on corn and provisions to wood ranch	1,075 00	
Making a total cost for the 5,100 cords		$61,806 00

Cost at mill of 5,900 cords of wood by Ropeway:

5,900 cords of wood, delivered at Upper Terminal, at $2.20 per cord	$12,980 00

Cost of delivering same by Ropeway (as above)	3,571 50		
Making a total cost for the 5,900 cords		16,551 50	
This leaves a saving for the first year of			$45,254 50
Additional items of saving:			
In delivering charcoal		$1,350 00	
In delivering boards and lumber		1,460 00	
Allowance for return freight on corn and provisions		1,075 00	
Of the 5,900 cords delivered, 800 cords were sent to the mine by return freight, on mules that brought down ore, saving		3,840 00	
			7,725 00
Thus making a total saving for the year of			$52,979 50
Deducting the cost of constructing Ropeway			19,400 00
Saving to the company at the end of the first year, after deducting the whole cost of Ropeway			$33,579 50

Six years' experience has afforded the writer opportunities for studying the causes of wear and the difficulties to be contended with in operating wire ropeways upon steep grades. The slipping of the clips on the rope is the most fruitful source of delays in operation; the contact between the clips and sheaves, the chief source of wear and the main obstacle to the life of both rope and sheaves. The cuts shown upon the following page illustrate the form of clip, which has been devised to remedy these evils.* They are not the clips used on the Plomosas ropeway, which were of the Hallidie pattern.

The clip is made in two parts, B and C, which are connected with a pin, H, thus forming a hinge that opens upwards.

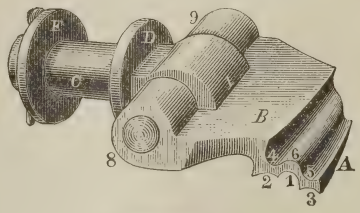
On the extreme end of the body, B, is the spiral web, A, that

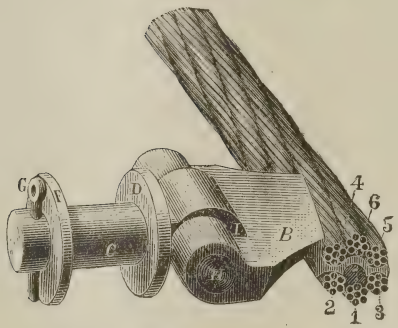
* Manufactured from the author's design by the Vulcan Iron Works, San Francisco. This firm also manufactures a simple loading device for filling buckets on the ropeway automatically, which can also be used to transfer the load from the buckets of one ropeway to those of another, which would be necessary provided the length were more than three or four miles (depending, of course, somewhat upon the amount of material to be handled in a given time.)

enters the rope. On the other end are two prongs, 8 and 9, which are drilled to receive the pin, H. The part C has on one end the round shaft C, on the other end is the lip I, that seats on the body, B, thereby forming a solid body in one way, while an obstruction touching the bottom, raises it up, as shown on Plate 4, lower figure, right hand side.

The spiral web, A, has concave corrugations 1, 2, 3, 4, 5, and the convex corrugation 6. This spiral is made to conform to the pitch of the strands of the rope and to the size of the strands also, so that the rope fits accurately in the corrugations.

No. 1 is to receive the heart or core of the rope, while 2 and 3 are to receive the two outside strands of the rope. The third of the three bottom strands lies underneath the heart, which lies in the score 1.



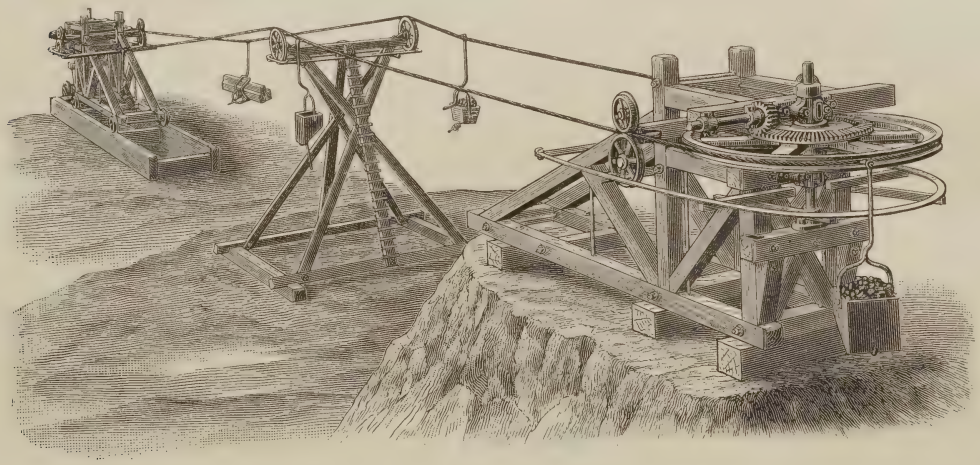


The convex corrugation 6, on the top side of the web, is to take the place of the upper half of the heart. Nos. 4 and 5 each take one strand of the rope, while the third lies on top of corrugation 6, thus forming an almost perfectly round rope.

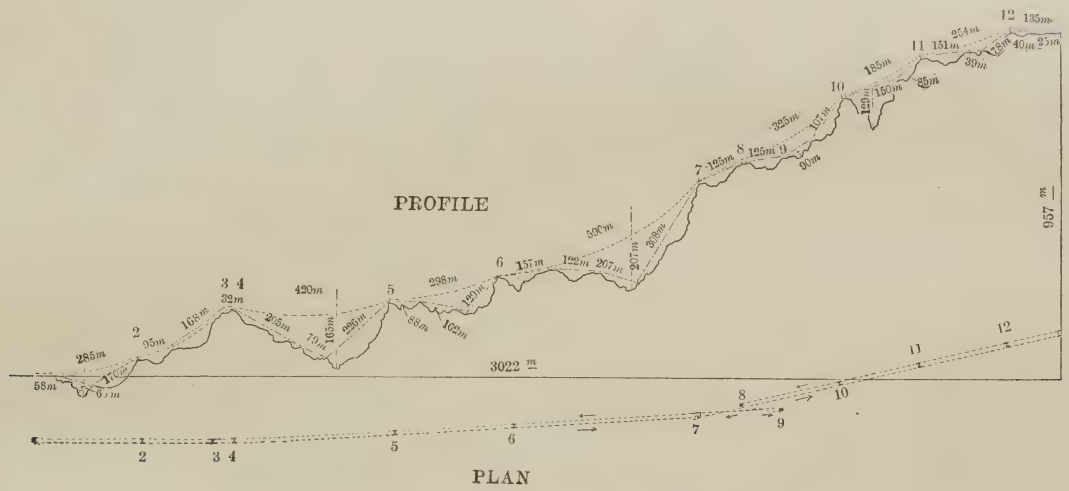
On the arm, C, is cast a solid collar, D, a loose washer, F, being placed on the end, with a split pin, G. Between the collars D and F goes the hanger, which carries the load.

The action of the clip, on coming to a sheave, is as follows: The body, B, comes in contact with the rim of the sheave, and is raised up as it travels over it. As it passes to the other side it falls gradually until the lip I comes in contact with the body of the clip, B. During all this operation the shaft of clip C remains in a horizontal position.

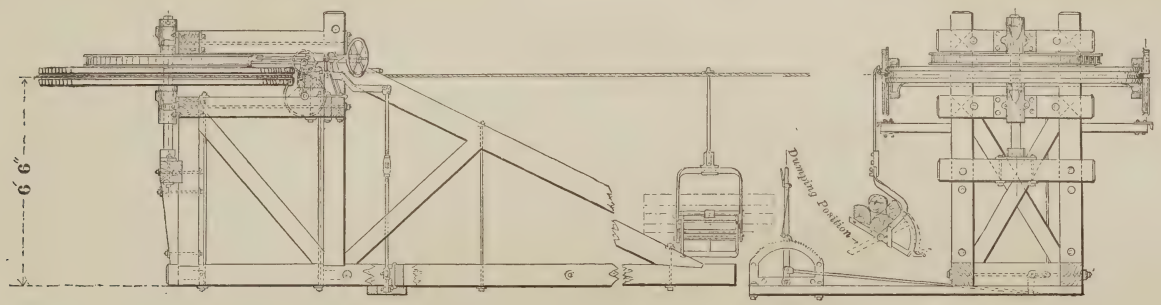
The clip being hinged, and inserted into the rope without changing its form at the point of insertion, presents no protuberance on the rope, and allows the clip on coming to the sheave to pass over it without jar to the rope or throwing the load out of its vertical position, and avoids the serious swinging motion occasioned by the use of rigid clips. The hinged form of the clip also admits of the use of deep, wide grooved sheaves, which prevent the rope from "jumping out," as is so apt to occur with the ordinary sheaves in use, the rims of which have to be kept cut down to one-half the diameter of the rope. Besides being readily attached to the rope, this form of clip has the peculiar advantage that it can be easily advanced on the rope from time to time, thus presenting a new portion of the rope to wear and prolonging its life. The clip is not expensive, and it has an advantage over other clips which need heating to bend them round the rope, which affects the temper of the rope and reduces its tensile strength.



Model showing Terminals, Intermediate Supports and Line in Operation.



Plan and Profile of the Plomosas Line. (Measurements in metres.)



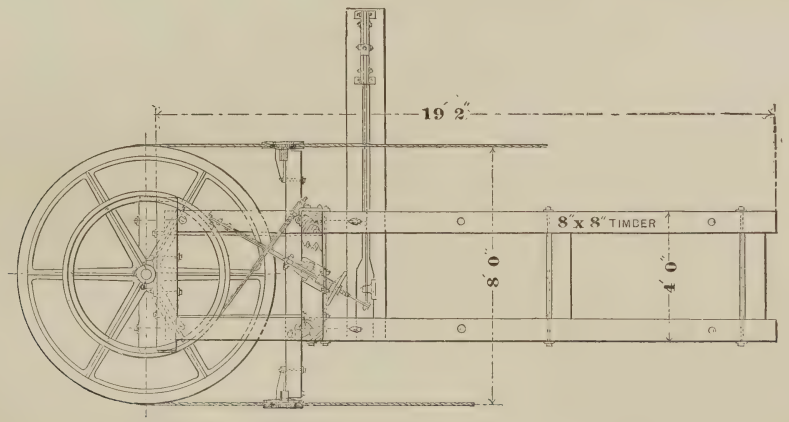
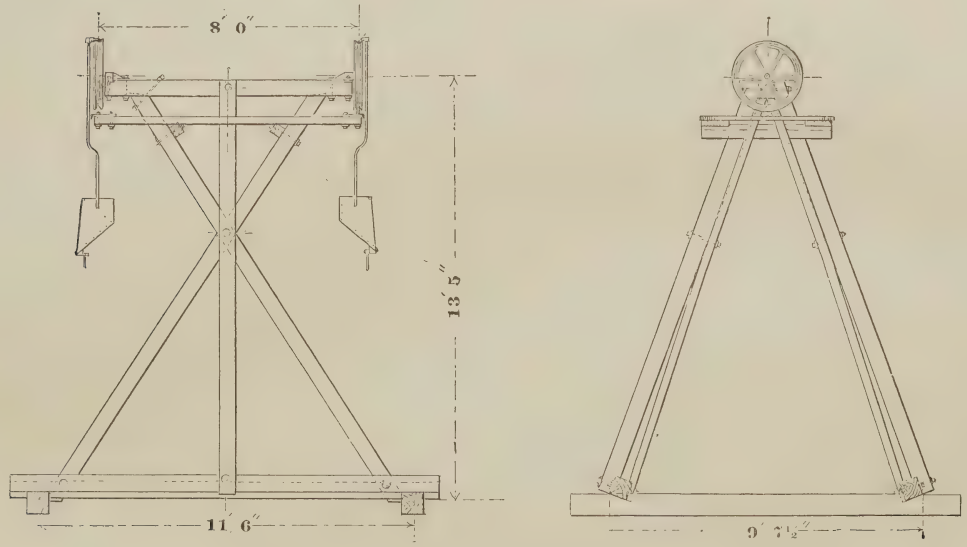


Plate 2.

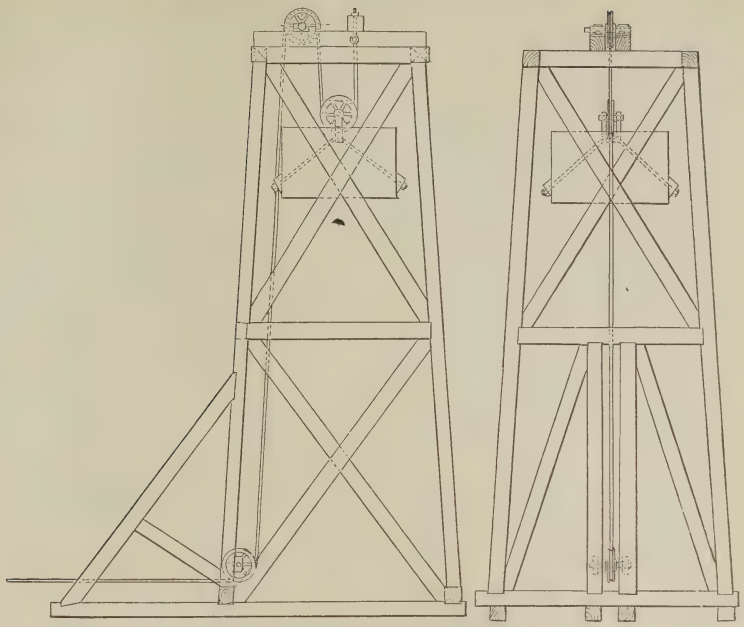
McINTIRE ON WIRE ROPEWAYS.

Plan and Elevation of Terminal Structures.

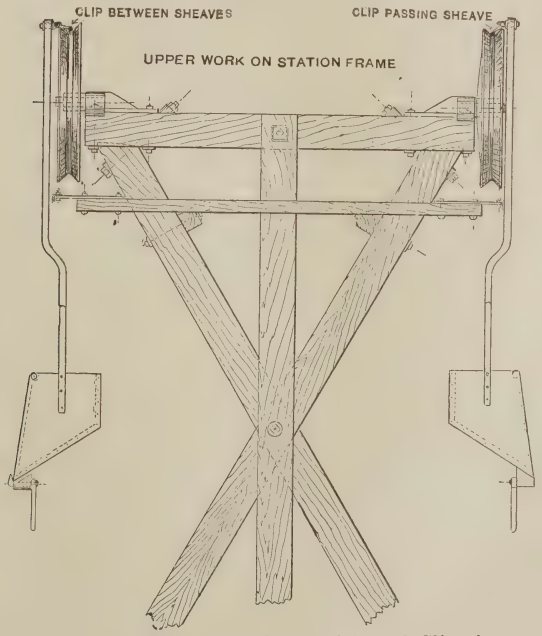
McINTIRE ON WIRE ROPEWAYS.



Plan of Trussed Supporting Structures or Station Frames.



Plan of Counter-Weight Structure.



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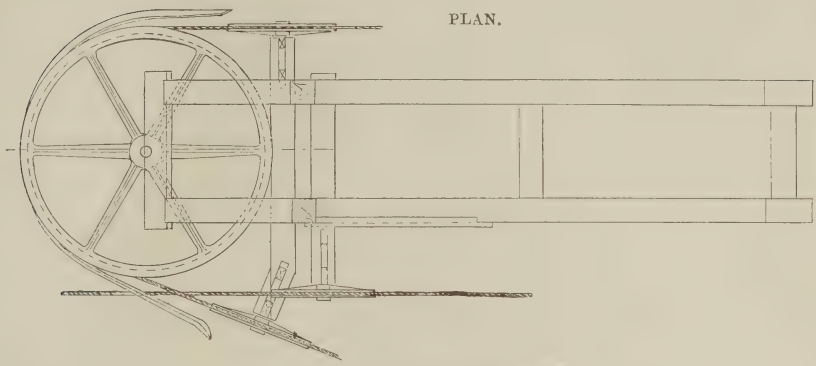
Details of Station Frames showing position of Clips in passing Sheaves and between same.

McINTIRE ON WIRE ROPEWAYS.

Horizontal Turn Sheave Structure to replace Post 8.



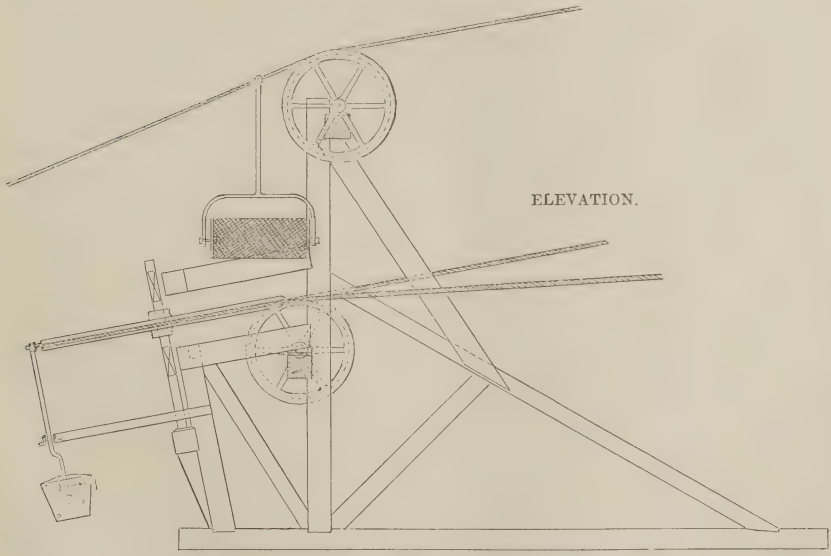
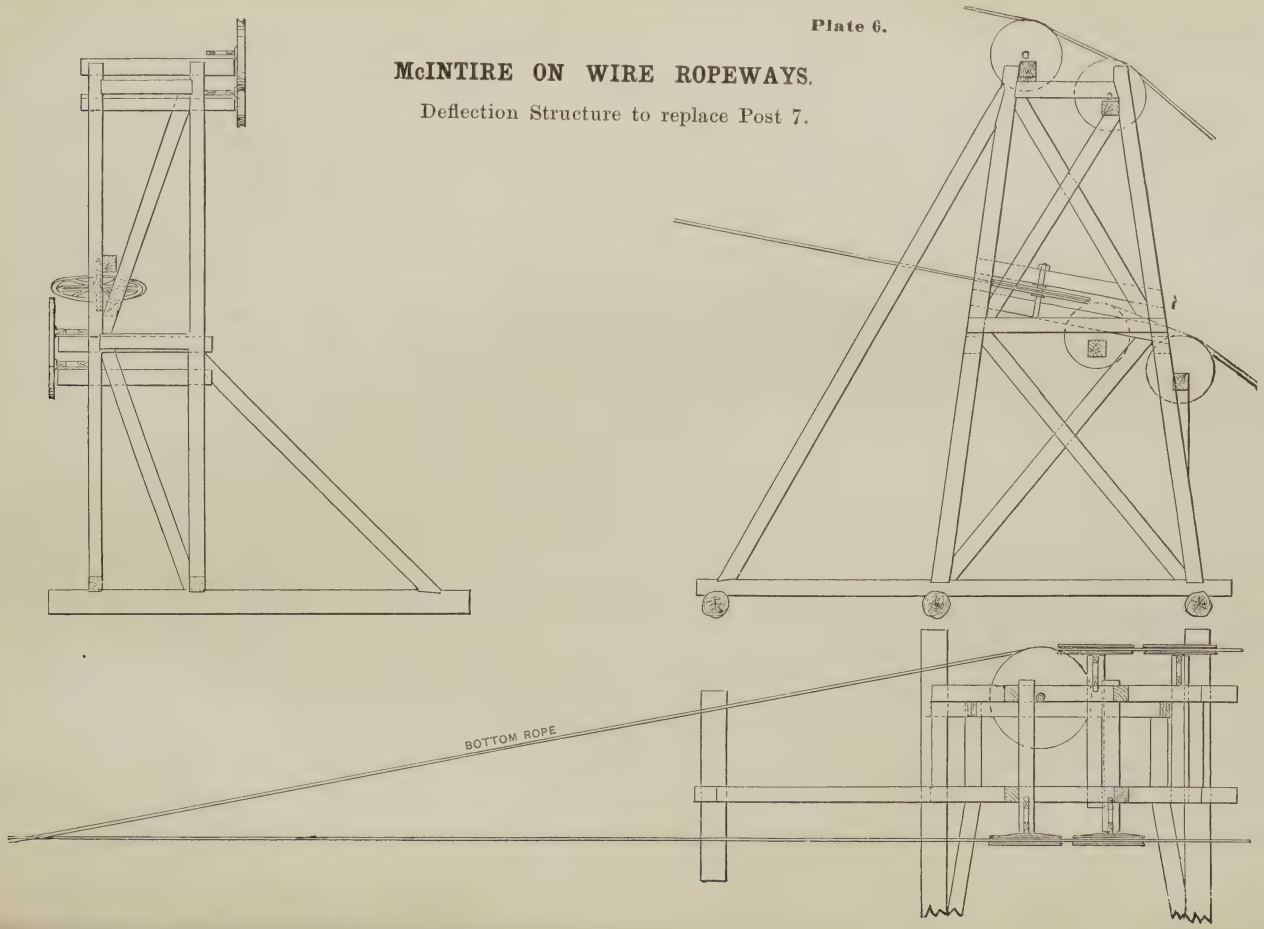


Plate 6.

McINTIRE ON WIRE ROPEWAYS.

Deflection Structure to replace Post 7.



TECHNICAL SOCIETY OF THE PACIFIC COAST.

INSTITUTED APRIL, 1884.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the statements and opinions advanced in any of its publications.

(VOLUME VII. No. 4.)

A DISCOURSE ON BALANCING CENTRIFUGAL PUMPS.

BY J. RICHARDS, MEM. TECH. SOC.

Delivered August 15th, 1890.

Balancing Centrifugal Pumps is the announced theme for my remarks, but before entering upon that subject I think it will be a matter of interest to the members to say something of the nature, origin and history of these useful implements, especially as this matter is not very well understood.

Centrifugal pumps are the latest invented among water-raising machines, if we except a few that are not widely known, such as that of Dr. Pohlé, for example. Other standard pumps are centuries old, and for a long time there has not been much change in the principles of their construction, but as remarked, centrifugal pumps are a modern invention, not dating back more than fifty years in any recognizable form.

I have said they are imperfectly understood, and to support this statement and in advance of saying anything of their history, I will refer to a report of the American Commissioners who were appointed to attend the Vienna Exhibition in 1873, to report on machines and manufactures shown there. This commission consisted, as now remembered, of five engineers, and among the rest, Mr. Robert H. Thurston, a very eminent engineer in this country.

I am not able to give you the exact words of the report, but the substance of it involves the following propositions:

First. Appold was the introducer of this class of pumps.

Second. They were mis-named "Centrifugal," because they do not operate by centrifugal force at all.

Third. They operate by pressure, the same as a turbine water-wheel.

Fourth. When people understand their method of operating we may expect much improvement.

Fifth. They should have disc runners, because the fan wheels will soon wear out.

Comment is not necessary; and I think in the face of this "information," now only seventeen years old, my proposition that the pumps are not understood, will be conceded.

The report mentioned goes on to say that they seem to be very simple machines, involving no intricacy whatever. I think the members of that commission are better informed now, at least it is to be so hoped. I once thought myself, that these pumps were very simple machines, but when I commenced the manufacture of them here in California, nine years ago, I soon found to my astonishment they were not simple machines at all, but on the contrary, very intricate machines, involving many peculiar principles and conditions that nobody would suspect until they tried the experiment of working them under high and low heads, and other varying conditions.

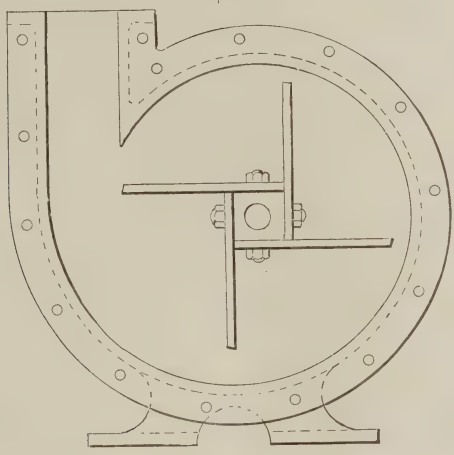
Prof. Unwin, who is perhaps as eminent as almost any living man in the science of physics and dynamics, three years ago, in discussing centrifugal pumps before an association of engineers in London, said, among a great deal beside that was very true and intelligent on that subject, that a centrifugal pump "is simply a reversed turbine water-wheel." In view of these facts thus briefly stated, I think there is a great deal to learn respecting centrifugal pumps, not only in a popular way, but among the engineers of this and other countries.

While the theories and principles of constructing such pumps seem to be reliable and correct mathematically, our present theoretical rules cannot in many cases be applied in practice, and it requires different proportions of various parts from what computation will furnish.

In respect to the diameter of the wheels, for example, I think

that so far as any theory of this matter has been laid down, that our fellow member, Mr. Luther Wagoner, has furnished the only premises by which the best practical results can be obtained; and at the end of what I have to say I will ask him to explain his propositions respecting a theoretical diameter of centrifugal pump wheels. Theoretical dimensions for the wheels are not, however, applied in practice; neither can the section of the waterways be made uniform. The curve of the vanes cannot have any rule because the form varies with the head, and there are other elements which have to be adapted to the circumstances of use in each case.

Fig.1



I promised to say something about the history of these pumps. Centrifugal pumps are, so far as I know, an American invention. A very good centrifugal pump was made in the United States as early as 1818, thirty years before any pumps of the kind were made in Europe. I do not know just where, but I think somewhere near Boston. They operated very successfully, and a number of them were made. In 1830 such pumps were exhibited in the city of New York at an exhibition held there. They were then called the "Massachusetts Pumps," and are illustrated in Fig. 1 of the drawings. As remarked, I have never been able to find out who was the inventor of the original Massachusetts pump. It was perhaps an "evolution" of a neighborhood.

In 1839 Mr. Andrews, of New York, improved the pump by applying the volute or spiral casing. This added a good deal to the efficiency at low heads, but nothing perhaps at high heads.

About that time Mr. James Stuart Gwynne, of London, now of the firm of Gwynne & Co., Essex street, Strand, in the same city, resided in the United States, and while at Pittsburgh, Pa., had his attention drawn to this Massachusetts centrifugal pump. He was a mechanic of some practice and of a good deal of ability, as he has shown since taking up the construction of centrifugal pumps as a business. He introduced the encased wheel, such as is shown in Fig. 4. The invention of encased wheels is due, however, to Mr. Andrews, an American, before mentioned.

About 1846 Mr. Gwynne went back to England, taking with him the centrifugal pump, called the "American Pump" in England at that time. He commenced its manufacture there, and very successfully. At the Exhibition of 1851 he was met in competition by Mr. Appold, whom the American Commissioners to Vienna claimed to be the first inventor of these pumps. I will mention here that in our country Mr. Appold comes in for a great share of the credit for inventing centrifugal pumps; but I am inclined to the opinion that he is entitled to very little credit in connection with the pump. He has never done anything but proposed curved vanes. Previously these had been made straight, or nearly straight. As to the value of that invention, I will digress a little and say something about the vanes, although this is hardly the proper place to introduce them; but I want to explain what Mr. Appold had to do with these pumps.

The diagram, Fig. 3, was submitted to an engineering Journal about three years ago by Mr. Charles Brown, of the firm of Sulzer Bros. of Winterthur, Switzerland, which I believe is one of the foremost among the machine shops of the world; I also think Mr. Brown one of the most eminent engineers living at the present time. In the construction of recent Government works in Italy, which are very extensive, he was selected by Sir William Armstrong & Co. to put down their novel and extensive plant, which was done in a very successful manner.

He says: "About 1856 I carried out a series of experiments to determine the best form and proportion for centrifugal pumps,

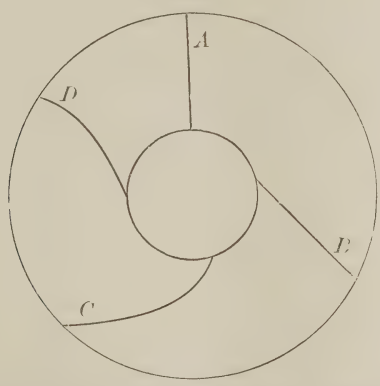
and found that the form of vanes had a great influence on the speed required. The sketch shows the form of vanes experimented on. The total lift was in all cases 45 feet. The inner and the outer diameter of the disc was as 1 to 3—that is, the inlet pipe was 10, and the diameter of the runner 30 inches, or those proportions. The water rose to this height, but without any discharge, and the wheel required a velocity in feet per second $= \sqrt{2gH}$ with the form of blade A. B required considerable more. C required still more. D required a velocity $= \sqrt{2gH} \times 0.82$. This you recognize as not the Rankine curve, but an approximation. D was the best in every respect, and I continue to use it.

(Signed) CHAS. BROWN.

September 17th, 1886."

The diagram, Fig. 3, is a reproduction of Mr. Brown's sketch referred to in his letter just quoted.

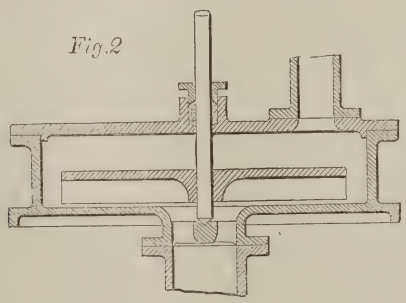
Fig. 3



I have introduced this matter here to show you how little Appold's curved vanes had to do with the improvement of centrifugal pumps. I will remark, that in my own experience the shape of the vanes does not involve a great deal. If a pump is working against a low head, I think that a flat radial vane is nearly as efficient as a curved one. The greater the speed of the wheel in proportion to the water, the nearer the vanes should terminate in a tangent.

An able firm, Messrs. Easton & Anderson, of London, took up Appold's plans and put them into competition with Gwynne, but declined to go into comparative tests at the World's Exhibition in 1852. Mr. Gwynne's firm being now a very strong one, they continued to control the market in England for these pumps; and it is my opinion that had Mr. Appold never seen a centrifugal pump the art would not have been much hindered, although Messrs. Easton & Anderson have made many large and successful plants, and are now prominent makers.

One more point in the history of centrifugal pumps deserves some attention, and that is the experiments of Mr. Bessemer, of steel fame. He was, as you perhaps know, for a long time identified with the designing of sugar machinery, and I believe is the true inventor of the centrifugal extracting machine. During his experiments with the extractor in London, he was led to the centrifugal pump. He invented and patented a system of centrifugal-acting pumping machinery, in which he ignored entirely the tangental energy of the water as it leaves the wheel. He thought that was of no use. We have an American invention of the same pumps fourteen years before Mr. Bessemer's. It is shown in Fig. 2, and was invented by Mr. Blake, of Connecticut, in 1831. All that Sir Henry Bessemer did was to modify the pump in various forms — ingeniously in some cases — to be driven by wind, water or steam. He wrote a long essay upon the subject. His pumps never had much efficiency for low heads; at high heads they might have done very well.



I will remark here that this long and tedious development of the centrifugal pump was characteristic of a past period; such a

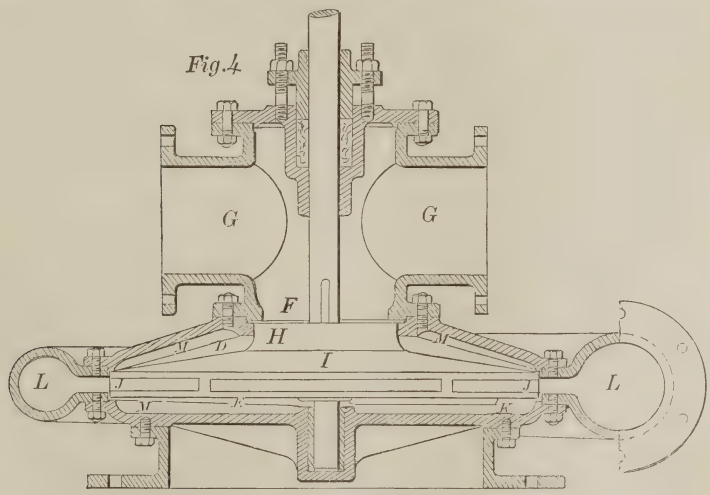
condition could not exist in our time. If this class of pumps were discovered at this day, they would no doubt receive more development in a single year than in the forty years that is covered by the facts recited.

We have a proof of this in dealing with so intricate and intangible an element as electricity. We have seen it, in all of its extensive uses put on a scientific basis, reduced to an exact art within a period of ten years or so.

I now come to the main subject.

"BALANCING CENTRIFUGAL PUMPS."

Among the phenomena that arise in working these pumps, is unbalanced pressure. We generally find, after making an unbalanced pump, that it burns out its bearings. This is sure to be the case if it is not supplied with the necessary balancing arrangement, the shaft and bearings are soon destroyed, because the pressure exceeds the limit allowed for bearing areas.



I am referring now to a disc like the one in Fig. 5. But before I speak of this pump, I will mention in connection with Fig. 4, that this encased runner or wheel, an invention of Mr. Andrews, was one of the things that James Stuart Gwynne took to England and introduced in his first pumps, and continued to

manufacture for several years, but subsequently abandoned. Neither he nor his brothers John and Henry Gwynne have made encased runners for twenty years past; using only open wheels.

Fig. 4 is a vertical section through a pit pump, as it is called here in California, from designs of mine made four years ago.

The water enters by double inlets G, at the top of the pump, and then through the nozzle H, to the interior of the wheel I, and is discharged at the periphery J, into the casing L, against a pressure due to the head. The heads are from 50 to 90 feet, and if, in this case, we assume 60 feet, then the pressure at J, J, and also in the spaces D and E, above and below the wheel, is $60 \times .43 = 25.8$ lbs. per inch static, or about 30 lbs. working pressure per inch of area.

Suppose the wheel I to be 30 inches diameter, then the area 706.8 times 30 (lbs. pressure) gives 21,204 lbs., or more than ten tons of pressure on each side. Following this matter of internal pressure further, suppose the casing J to be 40-inch diameter, then the pressure on the top and bottom plates will be about eighteen tons. This seems enormous, and it is also in a sense anomalous, because if the wheel I is changed to the form shown in Fig. 6, there is no lateral thrust on it at all, and the pressure on the casing J is nothing, or negative at the center, and the whole less than one half that before estimated.

Now as to balancing, we will return to the wheel I, Fig. 4. It has been explained how this wheel sustains on its sides a pressure of 21,204 lbs., working under a head of 60 feet, and a speed of $10\sqrt{60}=77.4$ ft. per second, but the whole area of the sides is not exposed. The inlet F, must be deducted from the top side. The diameter of the inlet nozzle H is commonly made one-third that of the wheel, and in this case 10 inches, so that this area, 78.5 square inches must be deducted from the top side, and represents an upthrust of about one ton on the wheel. This is enough to sustain the wheel, and a shaft $2\frac{1}{2}$ inches diameter, 60 feet long, with its couplings, pulleys, etc., and now we come to that point which suggested the discourse of this evening; the control of this thrust so as to balance such

pumps at different heads when they have the same area of inlet at F.

It must be remembered that in the quantities given, I have assumed that no rotation of the water, and no centrifugal effect takes place in the spaces E and D. This is the case when the runner or wheel is turned true and smooth as it should be, and fixed baffling vanes, M, are employed on the outer casing. It is evident that if rotation is set up in the spaces E and D, then whatever centrifugal force results, is that much toward balancing the pressure in J; hence the amount of upthrust due to the inlet at F can be regulated by the amount of water rotation under the wheel at E; and this is the method I have adopted in these pumps, applying shallow vanes, K, on the bottom of the wheel of varied length and depth to suit the heads under which the pumps are to operate.

This is a very sensitive kind of balance. In one case, in the Santa Clara Valley, one inch cut from the tips of the vanes, K, which were only $\frac{3}{8}$-inches square, made a difference of more than 300 lbs. in the thrust upon the shaft. If the space E is much widened by the raising of the wheel, then the effect of the vanes, K, is less, and the upthrust is cumulative, increasing as the wheel rises. This feature has been discovered during six months past in practice, and was not foreseen in my original plans.

One other feature I must point out here. In all pumps with encased wheels, there must or should be maintained a water-tight joint around the nipple, H. Any water forced back around this nipple will re-enter at the inlet F, and merely circulate in the pump. This is an objection to encased wheels, one hard to obviate, and should prevent them being used for pumping water containing grit or sand.

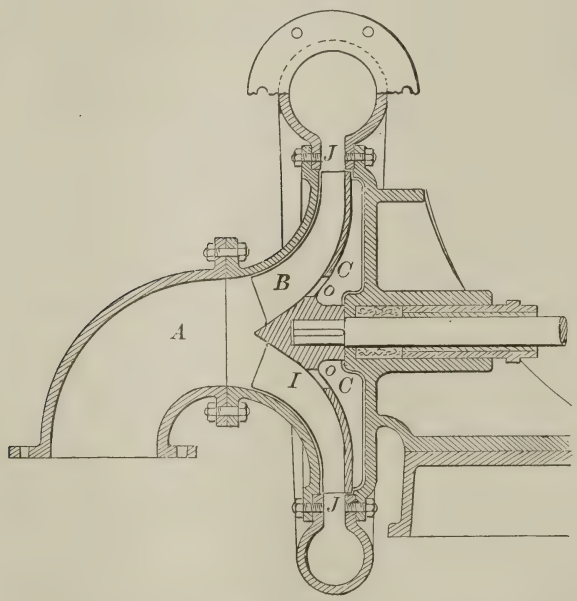
Referring next to Fig. 5, the pump shown is the result of six years' pretty constant experience as well as observation in this and other countries, and I think it will be a pardonable claim if I assume it to be one of the nearest approximations to theoretical practice that has been made up to this time.

The inlet, A, is at the side, so as to be accessible and easy to remove. The main casing, T, is volute in form and so constructed as to be set in any position on the frame.

The course of the water from A, through B to J, is by easy curves, and the area of sections is kept as nearly uniform as possible. The packing around the spindle is placed inside the main bearing, and there is, by reason of the concave form, but little overhang of the wheel.

Now as to balancing. The wheel, as may be seen, is a disc with vanes, B and I, on its front side. This disc, if 30 inches diameter, made solid, and without vanes C on its back would, under a head of forty feet, be subject to a lateral thrust as follows: Area of wheel, 706.8 inches; speed in feet per second, $10\sqrt{H}$; pressure per inch 19 lbs.=13,429 lbs.

Fig.5



This is impracticable, hence the wheel is balanced in the following manner: On its front are deep vanes, I and B, and on the back are shallow vanes, C. Now it is evident that centrifugal action is the same or nearly the same on each side of the wheel, but all the water passes on the front of the wheel. The rear or balancing vanes, C, are not quite as long as the main

ones, I. There is a difference of $\frac{3}{8}$-in. to $\frac{3}{4}$-in. at the tips, as seen in the drawing. This slight difference causes the centrifugal force on the front to overbalance that on the rear of the disc, causing a slow circulation of water over the periphery and through the holes, O, from the back to the front, just the reverse of what one would suppose.

Now I maintain that a pump thus balanced is as nearly in equilibrium as one with a forked or double inlet, and is more likely to remain balanced, because there is less danger of obstruction, and, as can be seen, the waterways are more direct and easy.

Thus it will be seen the working conditions of a pump are wholly changed by the kind of wheel employed. If the wheel is encased the whole interior of the pump sustains the discharge pressure. With an open wheel there is no pressure at the center, and only one-half as much on the sides of the casing.

Fig. 6

The friction is the same in both cases. With the enclosed wheels the friction is between the wheel and the water. With an open wheel, the friction is between the water and the main casing at the sides.

Except in cases like Fig. 4, where thrust is desirable, I am inclined to think that open wheels, or wheels with vanes on each side of central disc are preferable.

Fig. 6 shows an open wheel for a dredging pump, such as I have employed in a pump recently designed for the San Francisco Bridge Co. of this city, and also with a slight modification for a pump to be used in the harbor at Boston, Mass. These

wheels are made of steel and with five vanes, so as to admit stones or lumps of clay between them. There is no chance of obstruction, and in dredging there is no disintegration of the material beyond reducing it to the size of the discharge pipes. I have recently seen one of these pumps carrying more than fifty per cent. of solid matter.

Dredging pumps are commonly made with encased wheels, to prevent the vanes from breaking, but this class of pumps more than any other, requires open wheels. In 1885 I constructed in this city an open-wheel, single-suction pump, that ran for months without choking or accident.

Dredging pumps are also made with a double or forked suction, under the impression that this is required for balancing the wheel. This, as I have shown, is not necessary, and it need hardly be said that the tortuous passages and reduced section of the pipes, is extremely objectionable, causing frequent stoppages and accidents to pumps of this kind.

The wheel shown in Fig. 6 is strong enough to withstand blows from stones or pieces of iron that may enter the pump, and moreover is more efficient, and requires less power than an encased wheel.

The lateral thrust on a wheel of this kind is equal to the area of its shaft multiplied into the suction pressure, or about 80 lbs., just enough to keep the wheel in alignment if its bearings should wear.

In conclusion, I will say that centrifugal pumps have recently received a good deal of attention, and I think we are on the eve of having measurably fixed proportions for them. The size of the wheels for centrifugal pumps can probably never be made to correspond with the demands of theory, because the practical limit of speed for wheels is what the shafts and bearings will endure.

I have read all the literature I could find on the subject of proportions for the centrifugal pump, but I find no intelligent answer to the problem of the size of wheels except that of Mr. Wagoner before mentioned.

The limit of speed in these pumps is, as before said, to be found in their bearings; the size of the apertures are determined

by the obstructions that may have to pass through with the water; the thickness of the casing, and various other features, may be determined theoretically, based on the strains in most cases. What we will have in the end, probably, will be a compromise between the theoretical, commercial and operating conditions, and will settle down to something like uniform practice.

On this Coast I think we have done more to develop centrifugal pumps than all the rest of the United States put together; in fact, it has largely been done here during eight years past. The pumps that are being made in the East are constructed in many respects on lines taken from practice on this Coast.

DISCUSSION.

Mr. Wagoner—What is the greatest efficiency attained by centrifugal pumps?

Mr. Richards—The highest recorded efficiency is at Ferera near Rome, in Italy, where there is a very large plant, where it is 67 per cent. In Holland it has probably been a good deal lower than that. The efficiency of a well made pump should not be less than 60 per cent. Such pumps as are in the market—the "commercial" type—will not average over 40 per cent. I think centrifugal pumps are the most efficient we have under ordinary heads.

Mr. Wagoner—What is the highest head in use?

Mr. Richards—M. Farcot, of Paris, says his pumps work at 30 metres; the highest heads here are 95 to 100 feet. I do not know what the limit is; I think there is no limit determined.

Mr. Wagoner—What was the efficiency for such heads?

Mr. Richards—I am not able to say. I have noticed but very little difference in efficiency from a head of 60 feet upward.

Mr. Wagoner—I have paid little attention to the subject of late, but will say something of the points that have been touched upon. I do not think the action is that of a reversed turbine,

for in a turbine the water should enter the wheel without shock, and leave it without velocity, and that is impossible with any centrifugal pump. There might be room for improvement in pumps by adopting other forms. I have often thought it would be a matter of considerable interest to actually test a turbine wheel by driving it backwards.

Mr. Richards—This has been done and the efficiency was low.

Mr. Wagoner—There is another point in regard to balancing. Experiments at the University of California indicate that the work of skin friction from the water on a disc revolving like the centrifugal pump varies as the fifth power of the diameter and the cube of the speed. Experiments with various metals show that the skin friction upon almost all surfaces is practically identical, and varies from the 1.90 to the 2.08 power of the velocity (see Froude on resistance of skin friction).

Mr. Richards—I can see how the element of skin friction might enter into the efficiency of pumping beyond the high heads spoken of, but what its value is I do not know.

Mr. Wagoner—There appears to be no doubt that the proper velocity per second at the tip of the vanes is ten times the square root of the head for the ordinary form of blades. With 100, 200 or 300 feet head, one gets increased tangential velocities, and consequently more skin friction, and it strikes me the efficiency must drop off. I do not dispute the possibility of raising water to these heights, but at what cost, is what I would like to know. I know such pumps have been built and operated, but whether economically or not I have not been able to ascertain.

Mr. A. B. Bowers—I am greatly interested in the proper construction of centrifugal pumps, for, with me, it is a personal matter of dollars and cents, and for this reason I have given them more study than I otherwise would. Much has been written about them, and many interesting tests have been made, but correct principles of construction in many respects, have not yet, in my opinion, been fully arrived at.

The difficulty of balancing my sand pumps with a single inlet,

as they work under varying heads, has led me to build them with an inlet on each side, so that the pressure on the runner may be always balanced, whatever the head—for, let it be remembered, pumps with inlets on only one side are fully balanced only when working against the heads for which they have been specially designed. I think an involute is clearly the best curve for the inner ends of the vanes, and I have made, and am still making, experiments for the purpose of determining the best angle within which to generate this curve, not having yet arrived at a definite conclusion.

A radial vane gives a great shock to the water at its inner end. This is also true, to a considerable extent, of the Rankine, the curved or Appold, and even of the involute vanes, the latter being but the Appold vanes reduced to a scientific form.

The Rankine vane is thought by many to be the best now in use. It is recurved from the center, each curve being exactly alike and constructed to give to the vane a radial tip. I doubt whether this is the best possible form, though I do not care, at present, to say I have found a better.

Mr. Wagoner—What is the relation between the outer and inner diameter of the vanes?

Mr. Bowers—I made my first pumps with inlets one-third the diameter of the runner. In my later pumps the inlets have been somewhat larger. I use these pumps for handling sand, gravel, clay and dock mud. Sand and gravel cuts out the casing of the pump very fast. When my pumps have handled 500,000 yards of sharp sand they are completely worn out.

Mr. Wagoner—Have you used rubber?

Mr. Bowers—I have not. It has been used on the vanes of sand pumps with some success, but the wear in my pumps is mostly on the discs and casing, where rubber can not be so easily applied.

Mr. Appold has been credited with having made experiments with three kinds of vanes—the radial, one inclined at an angle of 45°, and the curved or Appold vane, the percentages of efficiency being given by him in favor of the inclined over the

radial, and of the curved over the inclined. Gwynn's pumps have radial vanes with tips turned backward, and are among the best in use.

In Germany, some vanes have been made running back very much farther than the Appold, extending through an angle (measured between radial lines) something like 120° or 130°. With these vanes it is necessary to drive the pump with great rapidity, and the efficiency, even then, is low.

There has also been tried, in Germany, a curved inlet, for the purpose of giving the water a rotary motion before its entering the runner—with a view of diminishing the shock at the inner ends of the vanes, and otherwise increasing the efficiency of the pump. To the suction pipe was given a peculiar curve of nearly three-fourths of the circumference of the inlet. I cannot give a correct idea of this curve without drawings. I have carefully looked for reports on the efficiency of these pumps, but cannot find that they are anywhere now in use, and doubt if they were very successful.

There is a recorded efficiency of 82 per cent. given for some centrifugal pumps at the Berlin Exposition. I am not certain whether that was the Gwynne pump, or that manufactured by Easton, Anderson & Co.

Mr. Wagoner—That report has been questioned by a number of people as to its truth.

Mr. Bowers—I doubt the correctness of the test. I know a great many centrifugal pumps show an efficiency of less than 20 per cent., and I think 50 per cent. is about as high as can be calculated upon with the best in the market. I think I am getting something over 60 per cent. with the pumps I am using.

Mr. Wagoner—What head?

Mr. Bowers—We have been discharging sharp sand at an elevation of from 10 to 20 feet above the water, according to the state of the tide, and through 3,600 feet of pipe. We have, day after day, delivered 5,000 cubic yards of sand, though this is above the average; on one occasion, in 23 hours, the delivery was a little under 9,000 yards. The cut made in that time was

14 feet deep, 210 feet wide, and 85 feet long: 14x85x210= 9,252 yards, but a slight inequality in the surface of the bottom reduced the output to a little less than 9,000 yards.

We know a great deal more now of the true principles upon which to construct centrifugal pumps than we did 10 or 15 years ago, but there is a great deal yet to be learned, and there is room for careful and exhaustive experiments. I propose, as soon as I find time to do so, to make an extended series of experiments, with the hope of finding out something more than I have been able to gather from the literature on this subject.

I am not yet satisfied with the ratios between the inlet and the diameter of the runner, the best width of vanes, or the best angle within which to lay them out. These are points, I think, which need careful testing. Most of the other principles upon which the pump is constructed may, I think, be considered tolerably well settled.

Mr. Wagoner—I will make this the subject of a special paper, as I have not time to go into it to-night. There is no question that the work of skin friction increases as the fifth power of the diameter, and that amounts in high velocities to considerable. Therefore it is imperative to reduce the diameter down to a minimum; on the other hand, there are other factors which come in to prevent reduction to small proportions.

I think that Mr. Richard's point is well taken, that there is a commercial factor that enters into it.

Mr. Jackson—I have made a good many designs for pumps, and a great many experiments for my own information, and I have decided if I were to make a runner in proportion to the inlet, I would make it just twice the diameter of the inlet.

I have tested pumps up to 100 feet head, and the efficiency does not vary enough to be measurable.

Mr. Bowers—In laying out the water-way passage of the pump, I give a large clearance at once; then I divide the periphery from there around to where the discharge has its full size, into twelfths, giving an increasing area for the increasing amount of water flowing through the water-way of the casing as it approaches the point of delivery. We should enlarge the casing

only as fast as we enlarge the quantity of water to be carried in it. My object has been to prevent back pressure in the waterway from the water issuing from the runner, and to give this water abundant chance to get out.

Mr. Wagoner—Is it your idea that the vanes act in two ways —by centrifugal force and by impelling action ?

Mr. Bowers—I think so.

Mr. Richards—The diameter of the runner, as I understand it, is not one of ratio to the inlet at all. The inlet is contingent on the volume of water that passes into it, and the speed with which you want to move the water.

I will not anticipate Mr. Wagoner's figures further than to say, that he has in one instance examined a pump where the water was carried to 1500 degrees before it was discharged. Whether that was right or not I leave to your imagination. That pump is working here now, and it will give you a clue to Mr. Wagoner's premises for computing the diameter of the runners.

Mr. Wagoner has raised the question of tangential energy, forgetting, I think, what he said about the ratio between the periphery of the runner and the discharge current in the casing. If we reduce the diameter of the runner, we do not reduce the skin friction in proportion, because there is the increase of speed.

Mr. Jackson—I wish to ask Mr. Richards how he explains the loss with an incased runner. Whatever water leaks through is circulated and represents waste. I infer from his illustration that the open runner did not have that waste.

Mr. Richards—In reply to Mr. Jackson's question about circulation, when the whole contents of a pump are revolving inside, there is no chance for circulation in the pump and no chance for the water to go back or circulate.

The form of the blades, which Mr. Bowers has mentioned as one of the questions to be determined, I think is based on the head; in other words, the ratio between centrifugal force and mechanical push of the water. I think the experiments tried by Mr. Brown, and others, shown in figure 3, are sufficient to prove

there is no fixed form for veins, unless you assume the speed of the runner in relation to that of the water in the casing.

Mr. Bowers gave the following account of a pump on a dredging machine constructed by him and now working in Tacoma, Wash.: Runner 6 feet in diameter; 6 recurved vanes in the flyer; thes uction pipe 20 inches, and discharge pipe 18 inches inside diameter; inner breadth of the vanes at the hub 17 inches, and at outlet narrowed to 6 inches. The cutter allows nothing larger than 5 inches in diameter to enter. Number of revolutions of pump from 160 to 185. The horse power runs from 160 to 190. 20,000 gallons per minute of clear water is discharged at an elevation of 10 feet; sometimes, when carrying a large percentage of sand not more than half this amount.

TECHNICAL SOCIETY OF THE PACIFIC COAST.

SAN FRANCISCO, CALIFORNIA.

INSTITUTED APRIL, 1884.

PROCEEDINGS.

(VOLUME VII.—No. 4.)

MINUTES OF MEETINGS.

REGULAR MEETING.

August 15, 1890.

Called to order at 8:30 P. M. by President John Richards.

The minutes of the last regular meeting were read and approved.

The following donations to the Society were announced by the Secretary: Official Report of the Fourth Annual Convention of the National Builders Association of the U. S. of America, held at St. Paul, Minn., January 27, 28, 29, 1890; Proceedings of the Canadian Institute, Toronto, April, 1890; Proceedings of the American Association of the Advancement of Science, 38th Meeting, held at Toronto, Ontario, August, 1889; Minutes of Proceedings of the Institution of Civil Engineers, Vol. C.

The following propositions for membership were read:

For members—Harold T. Power, mining engineer, proposed by John Richards, H. C. Behr and Ross E. Browne; Chas. J. Koefoed, mechanical engineer, proposed by H. C. Behr, John Richards and Otto von Geldern; C. I. Hall, mechanical engineer, proposed by John Richards, H. C. Behr and Otto von Geldern; James C. Gilfillan, mechanical engineer, proposed by H. C. Behr, Geo. F. Schild and Otto von Geldern; B. McIntire, mechanical engineer, proposed by H. C. Behr, John Richards and Otto von Geldern; Fredk. Orton, mechanical engineer, proposed by A. d'Erlack, H. C. Behr and Otto von Geldern.

For junior—Robert Edwin Bush, graduate College of Engineering, 1887, University of California, proposed by Ross E. Browne, H. C. Behr and Otto von Geldern.

A letter was read from Mr. P. H. Jackson announcing extensive experiments to be made in testing combination structures in concrete and iron, and inviting the members of the Technical Society to witness the experiments on Thursday, August 21st, between 9 A. M. and 5 P. M.

E. J. Molera, H. C. Behr and Hermann Kower were appointed a committee to witness the tests.

The election of Mr. Jason R. Meek, County Surveyor of Yuba County, as a member of the Technical Society, was announced, after a count of ballots.

The exhibit of the Electrical Storage Company having been postponed on account of the absence of Mr. Elder, their electrician, Mr. John Richards, after appointing Mr. Luther Wagoner to the chair, delivered a discourse on the subject of "Balancing Centrifugal Pumps," the stenographic report of which address and the ensuing discussion will be found in the printed proceedings.

An invitation was read from the Spring Valley Water Company of San Francisco to visit the concrete dam now constructing near Crystal Springs, Saturday, August 23d. It was stated that the San Francisco Chapter of the American Institute of Architects and the Technical Society of the Pacific Coast were jointly invited, and that Mr. Geo. W. Percy, a member of both Societies, was to be notified by those who desired to accept the invitation. Circulars to be distributed to all city members.*

The President announced that after adjournment the Board of Direction would hold a meeting to attend to special business.

Adjourned.

* This excursion took place on the day mentioned, in which quite a number of the members participated.

OTTO VON GELDERN,
Secretary.

TECHNICAL SOCIETY OF THE PACIFIC COAST.

SAN FRANCISCO, CALIFORNIA.

INSTITUTED APRIL, 1884.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the statements and opinions advanced in any of its publications.

(VOLUME VII. No. 5.)

A DISCOURSE ON CALCAREOUS HYDRAULIC CEMENTS.

BY CALVIN BROWN, C. E., U. S. N.

Delivered Sept. 5th, 1890.

Mr. President and Gentlemen—In accepting the polite invitation of the Executive Committee of your Society to address you on the subject of cements, I felt that in undertaking the task it would not be necessary for me to go into the matter to the full extent of its possible treatment. As engineers and architects, and in reference to the magnitude of its importance and applications in constructive works, all of you must have had considerable acquaintance with it, which supposition prompted me to limit what I ought to say more to my own experience than to attempt to lay before you, except in a very general and brief way, the details of its history, its chemical features and its economics.

Although the history of constructive engineering and architecture is marked by many interesting and even wonderful monuments of human skill, aided by science and genius, it appears to me that this nineteenth century in the discovery and application of hydraulic cements has far outstepped all previous centuries in the masonry of constructive works, taking into the account their utilitarian character, the rapidity of their erection

and their comparative cost even, to say nothing of the surmounting of difficulties of location never encountered by the ancient builders. In all these results the application of hydraulic cements has entered, and the modern architect and engineer find in this material an ally whose help remained beyond the reach of their predecessors.

The ancients have been popularly credited with the possession of superior cements, but as far as can be ascertained from history, and the investigation of their works yet extant, either whole or in ruins, there appears no evidence that their builders used any hydraulic cementing materials, except those found and applied in their natural condition after a simple pulverization, as pozzuolana, trass, etc.; all volcanic products which they mixed with common lime mortar to bestow a more rapid induration upon it and the capacity for hardening in damp situations or under water; they were not aware of, or at least they did not use, hydraulic limestone for the production of cement.

It was not until 1759, when the bold design of erecting a stone lighthouse upon the ocean-girdled Eddystone rock was undertaken by Smeaton, that the discovery was made by this able engineer of the existence of certain peculiar limestones which, when calcined and pulverized and made into mortar, possessed cementing qualities with the important characteristics of setting and hardening under water. His report of this discovery is given in the quaint language of old times: he says these stones after they are burnt and ground "afford a paste which hardens in a few days under water, but in the air they never acquire much solidity." It is reported that Smeaton discovered the causes of hydraulicity in limestones, but I do not remember the explanation he gave of it, but am impressed with the conviction that its complete description was given by very much later investigators. Smeaton used the natural products pozzuolana and trass for his cementing materials, but it is believed that for the strength of his great structure he relied more upon his system of dovetailing the stones in the work than upon the cement he put between them, which evidently was applied to bed and perfect their joints and so far prevent the water of the ocean from penetrating the masonry and thus preventing its hydrostatic effects.

It does not appear from any records I have been able to meet that much progress was made in the practical development of calcareous hydraulic cements until about 1780, when Dr. Higgins, of England, published a small treatise on what he called "water cements." If I recollect rightly he used common lime mortar treated with certain materials that conferred slight hydraulicity, such as pounded brick, etc. Sixteen years after this, or in 1796, a quick-setting hydraulic cement, resulting from the ordinary processes of burning and grinding certain limestones, was introduced by Parker, of England, and patented by him; he called this Roman Cement, under which name the article has continued in use down to this day, illustrating the charm of an impressive cognomen.

From the date of Parker's discovery forward, much attention seems to have been given to the search of limestones capable of furnishing a similar material, the general interest therein prompting several savans in England and on the Continent to engage in the work, the most conspicuous among them being the engineer J. L. Vicat, of France, whose elaborate researches commenced about 1812.

Vicat's well known publication shows how exhaustively he pursued his experiments, going into all the details of manufacture, manipulations and application of calcareous mortars, both hydraulic and non-hydraulic. Originally confined to the examination of materials which, taken in their natural state, yielded by the ordinary processes of calcination and pulverizing, cements of various qualities as to their powers of induration and hydraulic energies, his operations finally resulted in the grand discovery that although nature furnished throughout her lithological stores vast deposits of substances that in their natural state would supply a material with hydraulic properties, it was in the power of science to evolve an artificial combination of her various materials that in the highest degree would obviate the uncertainties of these single substances and secure a product at once adapted to all the purposes of the builder. It was well known that no pure limestone or simple carbonate of lime would furnish an hydraulic mortar, and in the fact that impure limestones would furnish such, though in varying degree, lay the hint that Vicat seized

upon, namely, to ascertain what was the element or elements that at the same time contaminated the limestone and conferred upon it, upon proper treatment, that wonderful property of plasticity, adhesiveness and hardening under water. Analysis showed that these stones were a mixture in various proportions, of carbonate of lime, alumina, peroxide of iron, silica, etc., wherein lay the principle of hydraulicity, and hence, by an artificial combination of these ingredients, it was possible to manufacture an artificial hydraulic cement whose efficiency as a building material might be uniformly secured beyond any chances involved in the capricious accidents of geological conditions.

Vicat carried out his experiments with a triumphant verification of their prophecy; he found their results like that shown in the natural stone to be a double silicate of lime and alumina, with certain traces of other substances whose presence in the composition might not be essential in its general characteristics though probably not impairing them.

I must hurry over the details of the subsequent development of Vicat's discoveries and simply mention that upon his views and experiments, several other eminent chemists and engineers in Europe entered upon similar investigations until almost the whole accessible domain of nature's rocks and earth was ransacked with the purpose of revealing other substances that might supply these invaluable qualities of adhesiveness and hydraulicity in building.

Vicat's system of manufacture of artificial hydraulic cements, or "lime," as he termed it, was soon installed, and in a short time several establishments for the purpose were set in operation. In these primary establishments they made use of quicklime and clay mixed in certain proportions with water into a paste which was then molded into briquettes, dried, burnt in a kiln and then ground.

It will thus be seen that Vicat's method involved two separate burnings, the first for the production of the quicklime used in the composition instead of carbonate of lime or simple limestone, and the second for the briquettes formed by the combination of quicklime and clay. This system was necessarily attended with considerable expense of fuel, time and labor, but became super-

seded by the method carried out several years later in England by Mr. Aspdin, who, by calcining a dried mixture of chalk and the mud obtained from a river bed, and afterwards grinding the product, fabricated the now well known Portland Cement. In the meantime other English engineers occupied themselves in experiments with the same materials, but Aspdin appears to have been considered as the inventor of the article under this name, which has been introduced all over the world, and so named from the color of its mortar which resembles that of the stone found in the quarries of Portland, England.

In the interim between Vicat's discovery of natural hydraulic cement and that of the artificial product, and up to within the last few years, the natural cements, more or less, continued to be used; but in Europe especially, and in countries where European builders manage the works, Portland Cement has almost completely displaced them. In the United States, especially in the interior and where it can be cheaply produced, the natural article still holds its use, but it may readily be seen that the Portland, wherever it can be procured, and in consequence of its great superiority must everywhere command the preference of the builder.

Time will not permit me, gentlemen, to extend these remarks to a complete description of the various methods of manufacture in different countries for the production of Portland Cement. I can only mention that the two ingredients of carbonate of lime and clay being almost universally used are found in different forms in the different localities where the article is manufactured. The carbonate of lime in the condition of a very pure and soft chalk is adopted in England where it abounds. On the continent of Europe chalk is also used where it can be obtained, but very many manufacturers there use a hard limestone either in a state of purity or otherwise. The clay, which besides the alumina, also contains the required elements of silica, iron, etc., is found in varying conditions, either as constituting the beds of salt water streams above low water level, or the soil of marshes, or as banks upon higher grounds.

In England the mixture of these two ingredients is effected by means of a heavy revolving harrow or stirrer operating in a cir-

cular tank, or wash mill as it is termed, wherein is placed the requisite quantity of water and a portion of clay as taken from its natural deposit. Into this wash mill, and after being properly pulverized and sifted, the chalk is introduced in right proportion to the clay. The charge of chalk and clay after a complete reduction of all the particles to an impalpable paste of semi-fluid consistency, is conveyed to large receptacles about 60 by 90 feet in dimensions and four feet in depth, and allowed to settle. Charge after charge of the chalk and clay mixture is thus prepared and placed in the receptacle until it is filled, the supernatant water of each layer being previously drained before a fresh one is added. The entire mass in the receptacle is left to acquire by evaporation a certain solidity, like stiff mud, in order that it may be shovelled into wheelbarrows and conveyed to the drying shed where it is spread in a layer of a certain thickness upon iron plates laid over flues, through which heat passes from fire places, which frequently are coke ovens, and supply the coke for the final calcination in the kilns. When the mixture or raw cement is sufficiently dried, it is broken in convenient pieces as uniform as possible and charged in layers of about four inches thickness into large and lofty kilns: between each layer and below the bottom one is spread a layer of coke of about the same thickness, and when the kiln is fully charged it is fired, the calcination occupying several days. Several days are also required for the cooling of the kiln so that the burnt "clinker," as the cooked cement is called, can be handled and sorted, the properly calcined being separated from the portions that are not so. The selected clinker is then conveyed to the grinding apparatus, ground, and thus converted to powdered cement.

The process just described is termed the wet process, and I believe is exclusively used in England, and possibly to some extent on the Continent, although in the latter country, and especially where hard limestone is employed, the system called the dry process is better adapted to this sort of material. In this system the limestone by grinding is reduced to an impalpable powder, and the clay after being perfectly dried is reduced to the same condition. These two materials are then mixed in the requisite proportion of about 78 per cent. of powdered limestone, when

this substance is a pure carbonate, and 22 per cent. of the dry powdered clay, these measures being by weight; they are then introduced to a pug mill with water and incorporated into a stiff plastic paste, which as it leaves the mill is molded into square and hollow prisms or briquettes of a certain size, which after being dried are calcined, as in the wet process, and then ground.

The perfection of Portland Cement, primarily, of course, depends on the use of the proper materials and the true chemical proportions of the lime and clay in the mixture. If these conditions are not observed good cement is impossible; their intimate mixture, depending upon the fineness of the particles to which they are reduced and the trituration to which they are subjected, is also an indispensable requisite, and lastly its calcination, which must be carried far enough to produce an incipient vitrification or welding together of these ingredients. The grinding of the "clinker," as the result of the burning is termed from its resemblance to the blackish slag or cinder of an iron furnace or forge, is also important, as the degree of fineness of the ground cement affects its practical economies in several particulars, both as to strength and its capacity for sand, etc. Here, gentlemen, is a sample of Portland Cement in the condition of the clinker; you will notice its great specific gravity, scoriaceous texture and blackish color. One would hardly suppose such a substance by simple pulverization could be converted into a cement of such vast and varied utility as experience over the world for more than sixty years has proved it to be. Had the ancient Romans, Greeks, Egyptians, or any other ancient peoples, possessed such a building material, old Vitruvius would have extolled it as the acme of their engineering and architectural triumphs and challenged the efforts of posterity to produce its equal. I must, however, quit these classical contrasts and hasten with the more essential matters.

I have to speak of the operation of burning the raw cement, as involving one of the most important essentials of the integrity of the finished product. This constitutes the most expensive part of the manufacture, besides demanding the most careful attention on the part of the burner. Various forms and systems of kilns have been designed, both of the so-called perpetual

and the intermittent sorts, the former being when the fresh charges of raw cement and coke are simultaneously fed to the kiln, as the thoroughly burnt portions are withdrawn, and the latter sort where the charge at once fills the kiln, and is not withdrawn until the whole of it is supposed to be completely calcined. These kilns are of numerous patterns, some of them still used are of fashions employed a century ago for burning quick lime. The so-called Hoffman kiln is an improvement on these antiquated forms, and is extensively operated for both building bricks and Portland Cement. Into all these kilns the raw cement is charged in either lumps or in briquettes, but a late improved system of burning has been introduced into England by Mr. Ransome, wherein the dried raw cement is reduced to small particles and exposed to heat in such a manner that they are quickly converted to the clinker state, thus saving much of the time occupied by the older methods and facilitating with greater economy the operation of grinding.

Coke is the usual fuel used in burning. Ordinary coal will not answer the purpose, as the sulphur commonly contained in it would combine with the lime of the raw cement and thus tend to the production of a sulphate of lime and consequently of a cement of too rapid setting. For the production of the clinker an intense heat is necessary, which must be carefully regulated, in order that the calcination may be uniform and without overburning or under burning the material, the product in either case resulting in a failure of good cement.

Of the immense variety of purposes to which Portland Cement can be applied it seems almost unnecessary for me to refer to before an audience of architects and engineers. The wonderful characteristics of the material, its crushing and tensile resistances, its plasticity and cohesion in manipulation and adaptation to all sorts of mouldings, even to fine statuary, and its persistent but slow setting induration with its apparently eternal durability, constitute the perfection of lithological building material both for its cementing bond, for all the various stones and bricks with which it can be used and for making blocks of stone themselves.

In this connection I must speak of the surprising discoveries

of M. François Coignet, of France, and his applications of what he calls Béton Aggloméré, a calcareous composition into which besides the sand, enters Portland Cement and hydraulic lime—it is an inexpensive artificial stone and is rapidly becoming used for edificial structures of almost every kind among that scientific and enterprising people. Seventeen years ago I witnessed in that country works of a boldness of design and extent that I could not have supposed to be feasible with a simple combination of mortar and sand. I have brought with me photographic illustrations of an aqueduct of nearly forty miles in length and supplying water to Paris built with this béton, the supporting arches as well as the water pipe itself being monolithically formed with it.* I had the good fortune to make the acquaintance of the engineer of this original and magnificent work, and was enabled to visit and inspect it at several points; the arch over the Orleans road, through the Forest of Fontainebleau, which I examined, was about 125 feet span without a joint in its construction. The only materials used in the construction of this aqueduct were Portland Cement in a very small proportion, hydraulic lime and the sand found along the route of the work. Another photograph shows a view of the church at Vesinet, also from foundation to the top of the surmounting cross built of the Coignet Béton. I might, if time permitted, mention other public massive works which I examined in France, all erected by the use of this material.

I have introduced these brief details of the history, manufacture and application of Portland Cement, gentlemen, supposing they might interest such of you as have not had an opportunity of an acquaintance with the subject in these particulars, and that you might find in them a recommendation for the extension of the application of this useful material in your own practice. I have felt obliged to omit many details in this part of my task which, however, you will readily find described in the literature devoted to the subject in French, English and German publications. I will now proceed to state my own experience both in the experimental manufacture and use of this valuable material.

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*Mr. Brown exhibited photographs of the works referred to in his discourse.

My interest in the general subject of hydraulic cement was awakened by my acquaintance with Col. Sylvanus Thayer, of the U. S. Engineers, in 1840. I think it is to this eminent engineer we are indebted for the extensive introduction into the public works of the United States of this material in the preparation of concrete, although in his time we had only the natural cements of which the "Rosendale" constituted perhaps the most popular brand, the Portland not being then known in this country. I had no opportunity, however, for experimenting in the production of hydraulic cement until I came to California in 1861. The Benicia manufactory was then in operation, being the only one for making hydraulic cement on this Coast, and turning out a natural cement which could be mixed for mortar or otherwise in only small quantities, for use, on account of its rapid setting and hardening. The contrast of this native cement with those of slower induration I had employed in the East, led me to suspect there might, in other localities of the State, be found a substance that would yield a less energetic hydraulic cement. I set about their discovery and collection and subjected various specimens to treatment with varying results. I pursued these investigations for several years, ascertaining that the country abounded with hydraulic limestones, calcareous marls, etc., several of them capable of furnishing cements equal to any then imported article. I also found that several of these limestones would supply, in large quantities, a superior hydraulic lime like the celebrated Theil and Seilly limes so extensively used in Europe and to some extent in the eastern part of the United States. This hydraulic lime as I found it was both of a pure white, like ordinary quicklime and also of a soft buff or cream-color; it will not slack in water like common fat lime and therefore would require grinding for purposes of mortar or other use.

Upon my return from a visit to Europe in 1873, where I had the best opportunities for observing the manufacture and application of Portland Cement, I occupied myself in experiments to determine the resources of this coast in regard to their adaptability to its production, an inquiry about which I had little doubt in consequence of my knowledge of the abundance of

natural materials I had previously found here. In these experiments I realized the necessity of a strict observance of the chemical principles involved in the production of the article, and amid the great variety of materials eligible for use, realized the importance of chemical analysis in each case in order to determine their proper combination. Every grade of limestone, from that of almost pure carbonate down to that mixed with various ingredients of alumina, magnesia, silica, iron, etc., I found to exist abundantly in the State; a calcareous tufa was also found in several localities well adapted to the manufacture, and I was also presented with samples of a native carbonate of lime in a pulverulent condition said to exist in abundance in the southern part of the State. Suitable qualities of clay, as shown by their analysis, were also found in large deposits, so that the presence of all these native materials gave undoubted assurance as to the feasibility of the desired manufacture.

In my operations, besides a careful observance of the involved chemical conditions, I found actual experience in manipulation to be the only means of acquiring a correct judgment in some of the more critical details in order to obtain satisfactory results. Such practical knowledge cannot be learned from any literature I have come across, nor could I obtain it from my correspondence with foreign manufacturers either in England or in Germany. After many trials, especially in the operation of burning, I succeeded in establishing a process that gave uniform and satisfactory results, and thus demonstrated the certainty of the native resources of the State for the supply of a superior Portland Cement in all the abundance that its building interests will ever require. By referring to the notes of my operations, I could show you, gentlemen, the record of samples of cement made from California materials that far excelled in tensile strength the average of the reported trials made in foreign countries. I have the record of samples, which after an immersion in water of 28 days stood a strain of 720, 786, 803, 806, 985, 988 pounds to the square inch, one sample going as high as 1112 pounds to the same area before it broke. All these specimens were subjected to the strains of a perfectly correct and standard testing machine owned by Mr. William Jones of this city, who, with

other gentlemen, engineers and architects, were present at the trials. They were prepared from materials found on Mr. Jones' property in Alameda County, where they exist in great abundance.

Referring now to my experience in the application of Portland Cement to constructive works, I must take the occasion to express the obligations I owe to the late General B. S. Alexander, of the U. S. Engineers, for his sound recommendation to me to adopt a concrete in laying the foundation of the Mare Island Dry Dock, upon which I was then engaged. At that time, in 1872, Portland Cement was but little used on this coast; the only hydraulic cement we then, as a rule, employed, was the native Benicia and the imported Rosendale. This dry dock had been designed with a foundation of rubble masonry, in conformity with the usual practice in the buildings of the United States Navy, but subsequently, bearing in mind this able engineer's suggestion, and after seeing the widely extended use of concrete or béton in both foundations and superstructures in Europe, I determined to adopt his recommendation. In my first deposit of concrete to this work, and in the absence of Portland Cement in this market, I was obliged to use the Rosendale and the Benicia manufacture; but one day meeting an acquaintance in this city, who was an importer, I was informed by him that he had several hundred barrels of Portland Cement for which he could not find a purchaser, as nobody seemed to know anything about it, and would I buy it. I was glad of this chance for obtaining even so small a quantity as was offered of this superior article, and accordingly procured the authority for its purchase; it was the first I had used on a large work and proved so eminently superior to anything of the kind I had ever before employed that its preference became an established conclusion. The Government requisitions for it made at a time coœval with its demand for other purposes then about being introduced in this city, soon instituted its regular importation, and the market began to be well supplied.

You have lately been favored, gentlemen, with an account and description of the Mare Island Dry Dock, and I need only refer to its concrete foundation for the purpose of illustrating the method of its preparation. The essential features of this opera-

tion are the materials employed, their mixture and deposition in the work. Experiments were first made to determine the proportion of the materials, which were a hard and angular broken stone, of quite uniform size, tolerably fine beach gravel, and cement with the water, the object being to find the most economical quantities of these ingredients, especially of the cement which constituted the most expensive part of the mixture, at the same time the most essential one. It was also desirable to determine what quantity of the aggregate of the materials was necessary to be originally taken in order to make a given bulk in place after ramming, say a cubic yard. Thus, with the broken stone and gravel as the matrix, it was found that 13 measures of the former and 15 measures of the latter, or in actual quantities say $17\frac{1}{2}$ cubic feet of stone and 20 cubic feet of gravel with 200 pounds of Portland Cement and the water necessary for moistening the mixture, would exactly make one cubic yard in place after ramming. It will be seen in this case that the solidification by ramming was about 72 per cent. of the original uncompacted mass of the ingredients, and that the proportion of the cement in the solid concrete was about one in thirteen, or twelve of the stone and gravel to one of the cement. This concrete as thus prepared and laid in place weighed 144 pounds to the cubic foot, or very near the weight of ordinary well laid rubble masonry; the stone used in the concrete at Mare Island was very solid and heavy. When there was occasion for removing any portion of the concrete for obtaining a bed for the granite superstructure, it was found to be of admirable strength and hardness, requiring powerful efforts with sharp picks and gads for its displacement. It was absolutely impervious to water. Besides broken stone and instead of it, a heavy mixed coarse and fine river gravel of extra sharpness was used, with the economical result of requiring less cement than the combined broken stone and beach gravel—the quantity of gravel thus used as the entire matrix was $31\frac{32}{100}$ cubic feet, and of cement 157 pounds for one cubic yard of concrete in place, or about one in seventeen.

The concrete was mixed half a cubic yard at a time by means of its passage through a fall of about 37 feet in a tremie—this

convenient apparatus, available wherever a fall can be had for it, is fully represented and explained in the published transactions of your Society and needs no further account from me. Neither is it necessary for me to describe particularly the operation of depositing the concrete in place, except to intimate one or two precautionary observances, which should be taken in this operation, namely: where masses of concrete are required of considerable depth and are built of successive layers, each layer should have ample time for solid induration before the superincumbent one is added, each layer being kept wet and shielded from a hot sun, as a rapid drying damages the exposed surface by rendering it pulverulent and thus presenting to the succeeding layer an incoherent film, which prevents the bond that ought to exist in the joints between the two and so throughout the work. To reduce as much as possible, on account of the joints, the number of layers in a deep mass of concrete and at the same time to effectuate thorough ramming, the thickness of each layer should be regulated to meet those important conditions. We found at Mare Island that a layer of about 10 inches thickness was most favorable for the effective force of the rammers used on the work—a much thinner layer offering too little resistance for the prevention of a lateral scattering effect of the blow, while in a much thicker layer the force would not act on the lower portions.

Another observance, which seems necessary to intimate, is involved in the use of the water for mixing the concrete. It is to be remembered that the mortar of hydraulic cements is a hydrate and that its perfect crystallization requires an exact equivalent of its water, any excess being thrown off and any deficiency leaving it devoid of strength from incoherency. Recent investigations in France have shown that the ultimate strength of Portland Cement depends greatly upon the proportion of water used in its conglomerates or when mixed neat. In my own practice in making and testing neat cement, I have used of water from 20 to 33 per cent. by weight, of the loose powder, the smaller quantity giving the best results. In preparing concrete my practice was to add only water enough to a little more than moisten the whole mass, so that in ramming a very slight

excess would appear upon the rammed surface. The disadvantages of too much water are several. In the first place in the ramming a jelly like mass is produced rendering proper solidification impossible; in the second place, following of course the first named effect, the porosity of the mass renders it weak and pervious. These precautions are often overlooked by the ordinary users of Portland Cement conglomerates and in its neat applications; impressed with the erroneous notion that a large quantity of water is needed for a strong cement and not understanding the principle of its crystallization, they literally drown their mixtures thus placing them beyond proper solidification and rendering them honeycombed and weak. The entire system of mixing the ingredients of a concrete in the practice of certain operators is highly vicious; a pile of broken stone perhaps mixed with gravel or sand, or perhaps the gravel or sand alone, is spread and covered with a quantity of cement, more or less according to the guess of the workman, then turned or shovelled over when dry, and finally is deluged with water squirted through a jet nozzled hose which forces the cement to the bottom of the mass where most of it remains, rendering its equal dissemination impossible by any amount of hand shovelling in the effort of mixing. It ought to be obvious to the slightest consideration of the effect of this torrential treatment that the amount of water should be limited and carefully applied by the gentle action of a rose nozzle pipe; in this manner a stronger concrete would be produced and with a less quantity of cement.

In the manufacture of Portland Cement I have mentioned the importance of exact proportions of its ingredients as contained in the lime and clay. I have now to speak of the effects of their disproportions when they vary from certain narrow limits allowable in the preparation of the raw cement. It is evident that any undue excess, especially in the lime or alumina, causes the existence of an element which may not only be superfluous but detrimental; if there be an excess of clay or alumina added in the mixture the product is likely to be a quick-setting cement and deficient in strength. With European engineers one of the tests of Portland Cement governing its acceptance for their works is that it must not set within a given number of hours, except in

cases where a rapid set is required, as in water currents. It might seem that the initial setting is an indication of the subsequent hardness and strength of the material, the slow process promising best results in these respects. From certain native limestones abounding in clay, I have made a natural cement whose powder would instantly be converted to a hard stone the instant water touched it—placed under water it would remain for several months in this state, but upon being removed would crack and fall to pieces. An excess of lime in Portland Cement, or lime uncombined, results in a slacking process of this excess, which, taking effect in work built with the material, causes it to swell or "blow" as it is technically called, showing itself in reticulations upon the exposed surfaces and sometimes in cracks throughout. The obvious remedy for this excess of lime is to eliminate its causticity by the process of air slacking which is done by exposing the cement in powder spread in a moderately thin layer to the air for a few days before it is used. It is the manufacturer's duty to see that this aeration is done before the cement is packed for the market, and honest men of this class will not neglect it. Not fully confiding in the integrity of the entire fraternity of makers it was the practice at the dry-dock works at Mare Island to be certain of this aeration by exposing all purchases of cement to the process described. In illustration of the behavior of an over-limed cement when used too soon after its manufacture and the remedial effects of aeration, I have to show you this photograph taken of samples of my own preparation.

I am aware, gentlemen, that I have presented to you but a hasty and crude statement of the subject upon which I was invited to speak; knowing, however, that its more exhaustive treatment has been undertaken by abler hands and expressed in the extensive literature of your respective professions, I was conscious you could avail yourselves of this resource to supply the deficiencies of this brief address. It ought to be a matter of felicitation among you that massive concrete works have already been undertaken in this city, and that one of the members of your Society, and formerly its President, has had the boldness and sound judgment to propose and carry into practical con-

struction an original public structure by the exclusive employment of this material. It is to be hoped that we shall not long be dependent for the supply of Portland Cement upon foreign importation and that the resources of the State for its manufacture will be appreciated by capitalists and the necessary works for its production be established.

TECHNICAL SOCIETY OF THE PACIFIC COAST.

SAN FRANCISCO, CALIFORNIA.

INSTITUTED APRIL, 1884.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the statements and opinions advanced in any of its publications.

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EXPERIMENTAL WORKS FOR ORES REQUIRING COARSE CONCENTRATION.

BY H. C. BEHR, MEM. TECH. SOC.

Read October 3d, 1890.

The purpose of the following paper is to call attention to the importance of the proper examination of ores intended to be treated by coarse concentration and to show how simple and comparatively inexpensive a plant can be made to suffice for the necessary experiments.

The concentration of ores requiring fine comminution, particularly free gold ores, has reached a considerable degree of perfection in California, and our builders of mining machinery are well versed in all the details of the requirements. On the other hand, coarse concentration, such as is usually applied to lead and copper ores, has received until lately but meager attention. Some activity is now, however, being manifested in this direction, and engineers and contractors are beginning to realize the importance of being prepared to undertake the design and construction of plants adapted for this purpose.

It is generally easy to determine whether the treatment of an ore requiring concentration should begin with coarse sizes, or

whether in the start the material should be in the condition of sands and slimes or meals. In the latter case the necessary tests to determine the most economical degree of concentration can be made in almost any assay office. Some of these are provided also with machinery for experiments on a larger scale. Such tests can often be made at concentration works properly equipped. It is different with coarse concentration.

Before entering upon the design of the plant it is necessary to study the conditions, for these will indicate the course to be pursued in making the tests and designing the plant. These conditions are usually numerous and intimately connected with and dependent upon each other.

Aside from the character of the ore the following are generally the more important ones:

(1). Quantity of water at disposal;
(2). Capacity of plant required;
(3). Degree of concentration required;
(4). Nature of operations succeeding concentration;
(5). Proximity to mine or to water supply;
(6). Disposal of tailings;
(7). Cost of transportation of concentrates;
(8). Other conditions too special for general enumeration.

The quantity of water at disposal, and the desired capacity of the plant are usually the first things to be considered. The former often limits the latter. The degree of concentration has an important bearing on the extent of the plant. Where ores are concentrated for the purpose of saving in cost of transportation, the aim will naturally be towards rich concentrates; but where the operations following concentration are performed close at hand, the degree of concentration will frequently depend on the requirements of the subsequent process. For example, in smelting with cheap fuel, the extra cost of smelting the greater quantity of poorer concentrates may be less than that of obtaining the higher degree of concentration.

The disposal of tailings may have a bearing upon the choice of location and general design of the works, as well as proximity to mine or water supply. Where water is scarce, it is advisable

to drain the coarse portion of the concentrates and tailings, and pump the drained-off water back for re-use. In such a case the disposal of tailings will generally have to be accomplished by mechanical means or by manual labor, and ample dumping ground becomes desirable, and also sufficient grade below the works, so that the tailings will not have to be transported too great a distance.

The foregoing will serve to indicate the nature and extent of the necessary inquiries preliminary to experiments upon the ore or design of the plant.

The most economical course of treatment which the ore is to undergo, previous to and during concentration, is dependent upon the characteristics of the ore, and can very rarely be determined properly without extensive experiments.

Concentration really begins in the mine with hand sorting, and it becomes important to determine how far the operation can be economically continued, both on the cobbing floor before crushing and on picking tables after the ore has passed the rock breaker and wash trommel.

A general impression seems to prevail that all hand sorting is a costly operation. It is true that with our prices of labor the process cannot be carried on to the extent and with the refinement practiced in Europe. Notwithstanding this, paying examples do exist in the United States. At Tuscarora, Nevada, the writer has seen the ore from the North Belle Isle mine being spalled and hand sorted in a regular sorting shed. The *Mining and Engineering Journal* of April 14th, 1888, contains an article entitled "Ore Sorting," by F. L. Bartlett, giving an example of hand sorting of an ore containing cupriferous iron pyrites, rich copper ores, zinc blende and galena, with slate and quartz. When no separation of different minerals is aimed at, the work can be carried on very economically with sized and cleaned ores on revolving or shaking picking tables. One man can, with such an appliance, sort over a large quantity of ore, thereby increasing the capacity of the plant and reducing the tendency to form rich slimes.

By testing in a suitably arranged plant several tons of ore, representing an average sample of the mine, the question of

adaptability of the ore to hand sorting can be decided before entering upon the design of the intended mill.

An important factor in the design of a concentrating mill should be to determine by proper test how the mineral cleaves away from the gangue during crushing; also whether excessive comminution will be prevented by gradual reduction of size, and to what extent subsequent separation can be benefited thereby, and at what cost.

In a plant of small capacity the principle of gradual reduction can generally be only imperfectly carried out.

In an article which appeared in the *School of Mines Quarterly*, and also in *The Engineering and Mining Journal*, of March the 13th, 1888, entitled "The Dressing of Non-Bessemer-Ores," by G. W. Maynard and W. B. Kunhardt, is given a description of experiments made by these authors on iron ores with a view of determining the relative proportion of sands and meals with direct crushing, and with more or less gradual reduction. Mr. Luther Wagoner made some instructive experiments bearing on this subject, and gave the results with diagrams in a paper entitled the "Theory of Ore Crushing"; the paper was read in May, 1886, and can be found in the proceedings of the Technical Society.

It is also important to fix upon the coarsest jig-size and upon the decreasing scale of sizes to be worked upon the successive jigs, and upon the quantity of each and the relative proportion of headings and tailings in each size. Then the question of middle products and their treatment can be determined. Many other points will have to be decided, and from the foregoing it will be seen that the matter is rather intricate.

A test sufficiently extensive to give average results will, if properly conducted, generally afford all necessary information to determine, not only qualitatively but also quantitatively, the different features of economical treatment; so that the different departments and machines can be correctly proportioned to the amount of material to be handled by them for the desired degree of concentration.

Naturally the tests and subsequent design of the mill will be a simpler matter if the ore is only to be washed by eliminating

the gangue than when, in addition, several minerals are to be separated from each other.

In making tests with reference to coarse concentration it is not absolutely necessary to extend them to material finer than can be treated on jigs, for the reason that, if in a mill, when erected, the machinery for dressing the meals is not suitable, changes or additions can be easily made without affecting the preceding coarse part of the work. Changes in the coarse treatment would affect the whole mill below the point changed.

While preliminary tests are almost invariably made in the case of other metallurgical processes in this country, it is to be regretted that experiments previous to building concentration works are exceedingly rare. There would be less failures to be heard from, and many existing works would be more efficient than they are. European and American authors all agree as to the necessity of such investigations. In Germany they are invariably made, and the largest firm there, engaged in the manufacture and designing of concentrating plants, The Maschinenbau-Anstalt Humboldt, near Cologne, advertises that they have connected with their works an extensive experimental plant, where concentration tests can be made. The large plant erected by Prof. W. B. Potter for the Washington University, at St. Louis, shows that in other parts of the United States the importance of concentration tests is beginning to be appreciated. The writer is of the opinion, however, that such plants should also be connected with machine shops which are engaged in the manufacture of concentrating machinery, as in the case of the German firm mentioned, for, besides being a source of information and guidance in designing concentrating mills, the plant would be a permanent exhibit of the machinery manufactured by the builders, and could be shown in operation at short notice to demonstrate the efficiency of any of the machines; and it could also be turned into a source of income from the investigations, for which charges could be made; or it could be rented to parties who wished to make tests.

An experimental plant suitable for making thorough concentration tests is generally believed to be costly. This would be true of a plant designed like a regular concentrating works, with

all appliances for continuously handling the ore, and suitable for a large amount of business and for making tests rapidly. It is needless to say that the requirements for such a plant do not exist here, and that the money invested could not be expected to pay sufficient interest.

The writer has frequently felt the necessity of such works, and intends now to show how a plant can be constructed at a comparatively small cost, and at the same time answer for all the tests that may be required.

In the plant illustrated, manual labor is supposed to take the place of mechanical devices for handling material. The employment of manual labor in experiments of comparatively short duration is a different matter from its use in a continuously operating mill; and in a testing plant the interest upon and the depreciation of such machinery lying idle for perhaps long intervals, will more than offset the extra cost of labor. An important incidental advantage in connection with manual labor is the better possible insight at each step, and the greater facility for sampling and measuring the quantity of the products issuing from the different machines. In a continuous plant this would be somewhat difficult.

The plant illustrated in the drawing accompanying this paper is intended as a first suggestion, and arranged with a view of illustrating every part as clearly as possible, and not as the best and most convenient arrangement that can be made.

Prior to the test the ore is to be weighed, which is easily done, as it is generally shipped in bags.

To give an example of the working of the plant illustrated for an assumed case: The ore is delivered by means of the lift, A, to rock breaker floor, B. C is the rock breaker, from which the ore, crushed to about $1\frac{1}{2}$ inch or 2 inches, drops on to the shaking riddle, D, provided with a screen, the upper half of which has openings of $\frac{1}{2}$ to $\frac{5}{8}$ of an inch, and the lower half 1 inch to $1\frac{1}{4}$ inch. This riddle separates the material into three sizes, which drop respectively into the cars 1, 2 and 3, placed beneath it. While the shaking riddle is not so efficient as the revolving trommel screen, its first cost is much less, and the frequent changes of screen sizes necessary in an experiment can be ac-

complished much more rapidly; a small sash with screen cloth being inserted in the main shaking frame and secured by clamp screws.

The rock breaker product should be systematically sampled, either by hand or more properly by a mechanical sampler, and the sample bagged and labeled. In accurate experiments the three products from the shaking riddle should also be sampled to determine if, and to what extent, more or less close sizing separates mineral from gangue. The three products contained in the cars should be weighed separately to determine the quantity of each size. Empty cars are to be in readiness to push aside and take the place of the filled ones. The coarse product of the riddle contained in car No. 3 is run off and spread out upon a bench or table, where it is examined with respect to its adaptability to hand sorting on picking tables. The products of hand sorting should each be weighed and sampled. If only two products result the subsequent treatment will only include the poorer part. If more than two products are made, two or more of which require subsequent comminution and dressing, each of these must be separately treated.

The ore in car No. 2, together with that product of hand sorting requiring to be concentrated, and which by composition bears the nearest relation to it, is run on to the lift, A, and elevated to the roll feeder floor, E, where the ore is dumped, and when all the ore has been through the rock breaker and hand sorting completed, it is charged into the hopper of the roll feeder, F. The opening between the rolls, G, is adjusted to a size between the size of opening in the upper and lower screens on the riddle, D, below the rock breaker. For more gradual reduction it is kept at or near the larger size, for less gradual reduction at or near the smaller size. In the first case two passes through the rolls, G, will generally have to be made before all the material is ready for any mechanical sorting on jigs, material above $\frac{5}{8}$ of an inch being more rarely jigged. When the roll opening is kept at the size of the coarser screen on D, the contents of car No. 2 will not be sent through this first pass of the rolls, and in this case will not have been taken to the floor, E, but only that product of hand sorting which has been referred to. For a first

pass through the rolls the screens on the shaking riddle, H, suspended beneath them, will have openings in the upper half of about $\frac{3}{8}$ of an inch, and in the lower half of about $\frac{5}{8}$ of an inch. As soon as all the ore on the floor, E, has passed the rolls, the coarse product contained in car 6, with the material in car 2, is elevated to E, the rolls are readjusted to about $\frac{5}{8}$ or $\frac{1}{2}$ an inch opening, and the ore passed through, the screens on the shaking riddle, H, having also previously been exchanged for finer sizes of about $\frac{3}{16}$ or $\frac{1}{4}$ of an inch above and $\frac{3}{8}$ of an inch at the lower end. It is needless to add that weights and samples should here also be taken, as in the case of the coarser crushings.

Material of the size between $\frac{5}{8}$ and $\frac{3}{8}$ of an inch would now be contained at No. 6 below the rolls, and at No. 1 below the rock breaker. It is evident that for tests upon large quantities of ore too great a number of cars would be required. Storage platforms should therefore be provided at the hight of the cars above the floor, the cars to be elevated to these platforms and dumped, and when the material would again be required for further treatment it could be easily raked into the cars. The material contained in car No. 1 must now be passed over a screen, the overproduct mixed with the contents of car No. 6, elevated to the floor, E, and charged to the self-feeder, F; the latter being now connected by means of a spout, I, with the three compartment jig, J.

The jig for this run should have sieves of a mesh finer than the stuff fed to it, and the coarse stuff would be discharged through a gate made at the side or in the center of the sieve.

The speed of the jigs should be variable to adapt them to wide ranges of work. All the products from the jigs should be weighed and sampled, heads and tailings and middlings, as well as any products that may have come through the sieve and are caught in the hutches, N, below. In accurate tests the different sieve products should also be kept separate, especially when separation of different minerals is intended by jigging. The overproduct of the jig-sieves can be led to the same boxes into which the hutch products are discharged.

The other jig, K, can be rigged with a separate feed apparatus,

and all the $\frac{3}{8}$ inch size in car 4, worked on it in the same manner as the $\frac{5}{8}$ inch size; or if only one jig is used, that must be subsequently adjusted to the finer ores with reference to speed, stroke and mesh of sieve. All middle products intended to be crushed to finer sizes are to be held back until the regular stuff has reached the size to which the middlings are to be crushed, when both can be thoroughly mixed and worked together, or each be worked separately, the course to be pursued depending upon the character of the ore and the intentions as to the different classes of products.

In making jig tests a proportional part of the roll product can also be diverted, so as to drop directly into a car without being sized at all, or it can be diverted on to another finer screen. This can be reserved for a jig test on non-sized or imperfectly sized material. It will be seen how the test can be varied at will, and how, thereby, much important information can be gained.

The subsequent jigging operations can also be carried on with the remainder of the material after it has been properly sized over decreasing meshes of screens until the sand sizes are reached, which should be sorted in a rising current of water by means of the V-boxes, L and M. The best way to serve the material to this apparatus continuously and regularly would be by means of a centrifugal pump, which would also serve as a mixer. The two V-boxes deliver different sorted materials to the two jigs. For the final jigwork all the material is jigged through the seive and caught in the hutches; coarse material or ragging, through which to jig, being spread on the seives.

The treatment of the material finer than can be worked on the jigs, can be left out entirely, only its quantity should be determined and assays made.

The samples taken during the tests should be run through a grinder or small set of rolls and sent out to be assayed, and assays should be made as soon as possible after the samples are taken, as they may have a bearing upon the subsequent direction which a test should take, and by giving timely information save much labor and experimenting.

During the tests accounts should also be kept of the capacity of the different crushing machines, when crushing from one size

to another; also the capacity, length of stroke, and, if possible, the quantity of water used by the jigs for different degrees of concentration. The speed of the jigs should be uniform in order to obtain reliable results.

The rolls should be of first-class workmanship, and large diameter, so as to be suitable for a wide range of work. They could be arranged also to be run at two or more speeds, suitable for different ratios of sizes of material supplied and discharged.

In designing custom mills for dressing ores of different character, all of the ores that are intended to be worked should be tested separately to establish the limits of flexibility of the plant before the general design is attempted.

The machinery and other items required for the plant illustrated are given in the following list: 1 rock breaker; 1 set of rolls; 1 self-feeder; 2 three-compartment jigs; 2 shaking frames, with various sizes of screens and sashes; 1 centrifugal pump; 1 elevating hoist; 1 hydraulic separator; 4 to 6 cars; shafting, belting, etc., timbering, framing, platforms, water pipe and scales. To which may be added, a sample crusher and mechanical samplers.

The total cost of such a plant, erected in place, should not be much over $3,000.

Tests systematically made in the manner described and under the direction of a competent engineer can give all the necessary information for designing plants suitable for different percentages of extraction. The lower percentages, or those giving tailings less clean, are frequently the more important ones on account of other conditions affecting the total economy.

If possible, the men who are to manage large concentration works should participate in any tests instituted previous to designing the plant, so that they will be posted as to the general characteristics of the ores and the course of treatment decided upon.

Many concentration projects fail owing to the lack of insight on the part of the supervision, both in design and operation.

TECHNICAL SOCIETY OF THE PACIFIC COAST.

INSTITUTED APRIL, 1884.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the statements and opinions advanced in any of its publications.

(VOLUME VII. No. 5.)

HYDRAULIC BRAKE FOR HOUSE-ELEVATORS.

BY F. GUTZKOW, Mem. Tech. Soc.

[Read October 3d, 1890.]

In the following I present a full description of the hydraulic brake, which was the subject of a short verbal communication at the meeting of the Technical Society of October 3d, 1890:

The object is to secure the easy descent of the cage to the bottom if the hoisting rope or machinery should break, and, in general, a self-acting regulator of the speed of ascent and descent without the aid of mechanical attachments, springs, clutches, or levers.

The figure shows a vertical section of the upper and lower ends, the intermediate floors being broken away.

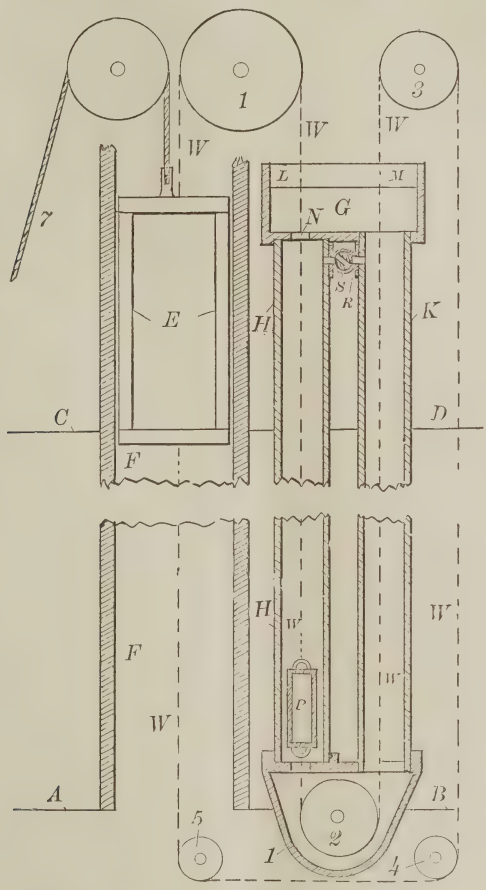
A B is the level of the basement-floor; *C D*, the level of the top-floor. The distance between these two lines is consequently the lift of the elevator.

F is the elevator shaft; *E*, the elevator cage.

The rope 7 represents the ordinary customary rope, which connects the cage with the hydraulic or other hoisting machinery.

The apparatus consists, essentially, of a U-shaped tube *H I K*, which is filled with water. The horizontal part of the U-tube is represented by the part *I*, which serves as a returning-elbow and contains the pulley or sheave 2. The two vertical branches of the U-tube are the pipes *H* and *K*, which extend the whole

height of the elevator-shaft. The open mouths of these two pipes are secured to the bottom of the open tank *G*, in which the water stands to the level *L M*. *H* and *K* are also connected together by a pipe *R* placed near the bottom of tank



G. The communication between *H* and *G* is contracted to the opening *N*, which is just large enough to allow a wire rope to pass comfortably through it. The area of *R* may be regulated by a stop-cock *S*. Through the rest of the apparatus the water

can circulate without restriction. The size or shape of *I*, *K*, and *G* are not essential as long as the dimensions are liberal.

The wire-rope *W* passes through the tube *H I K* and over the sheaves 1, 2, 3, 4 and 5. Its course is clearly indicated in the drawing by the dotted lines. It is endless, being fastened to the top and bottom of the elevator-cage *E*, and is as strong as the hoisting-rope 7. Inside the tube *H* this rope is interrupted by the piston or plunger *P*, which does not fit closely into the tube, but allows the passage of water through the annular space left between *P* and *H*. It is evident that (*E* and *P* being in the position shown) when the cage *E* sinks the piston *P* will rise, so that when the cage *E* is at the bottom of the elevator-shaft the piston *P* will be near the upper end of the leg *H;* also, that when the cage E ascends, the piston *P* is pulled downward by the returning rope *W*.

I shall refer, in the first place, to the descent of the elevator-cage from the position in the drawing. The water displaced by the rise of the piston *P* will escape from the chamber formed in *H* between *P* and the opening *N*, through the opening *N*, and through the annular space between the piston *P* and the leg *H*, the stop-cock *S* being considered closed. This outlet has been constructed too small to allow a free passage of the water, and consequently a pressure will ensue in the aforesaid chamber, which is indicated by a water-gauge or manometer connected with *H* near the top of that pipe. This pressure is reduced by opening the stop-cock *S* and brought under control. The stop-cock *S* is so far opened that the water-gauge shows a certain constant pressure during the normal speed of the piston *P*, say one or two pounds on the square inch.

The regulation by stop-cock *S*, as described, is required only once during the first trial of the apparatus. Now, every increase of speed of the cage *E*, and piston *P*, will increase also the pressure in the chamber between the piston *P* and opening *N*, because at the same time a larger volume of water has to pass through the same outlet as during the normal speed of cage *E* and piston *P*. The pressure of the piston *P* being thus increased, its speed is reduced. In order to illustrate still further, let the loaded elevator-cage *E* weigh eighteen hundred pounds, let the

normal speed of the cage be one foot in one second, the area of the piston P one square foot, and the normal pressure in the chamber between the piston P and opening N two pounds per square inch. Under this pressure one cubic foot of water will discharge through nine square inches of outlet. If the speed of the cage E and piston P should increase to two and one-half feet per second, the pressure in the chamber between the piston P and opening N will be two and one-half by two and one-half by two pounds, velocity being proportionate to the square of pressure, or twelve and one-half pounds, or eighteen hundred pounds on the one hundred and forty-four square inches area of the piston P—that is to say, the loaded cage is balanced. If, in the position represented in the figure, the rope 7 should break, the falling cage will be balanced after falling one inch, because according to the law of falling bodies two and one-half feet per second would be the speed then attained by the cage E and piston P. With this speed as a maximum the cage E will sink to the bottom of the shaft F, when the speed will be further reduced by the piston P closing the opening of R, or by a similar contrivance for reducing the outlet of the water when the piston P approaches the end of its possible stroke. In a similar manner the ascent of the cage E is regulated. What has previously been the outlet for the chamber between the piston P and opening N now becomes the inlet. If the piston P should move faster than the water can follow, it would work against the atmospheric pressure and also lift the water column existing between the level of the piston P and L M.

The dimensions given above are, of course, only chosen for illustration. In practice for a freight-elevator weighing, when loaded, say 1800 lbs., moving at $1\frac{1}{2}$ feet per second, the following dimensions are sufficient:

H is a 6-inch "casing" pipe, with $5\frac{3}{4}$ inch inside diameter.

P is 18 inches long and $5\frac{5}{8}$ inches diameter, its area consequently 24.8 square inches.

Normal pressure in chamber N P as regulated by stop-cork S=10 lbs. per square inch.

Normal counter-pressure on $P=10\times24.8=248$ lbs.

Velocity of water escaping around P and through N and S, with approximate calculation of the friction=20 feet per second.

Volume of water displaced per second $\frac{24.8}{144} \times \frac{3}{2} = 0.26$ cubic foot.

Area of escape for discharging this volume with 20 feet velocity=1.87 square inches, which is represented by $\frac{3}{4}$ square inch area round P, and as much round the wire rope at N, balance by the opening at S.

Should, by the breaking of rope 7, or by other reasons, the normal speed of the elevator-cage be doubled, then the pressure in the chamber $N\,P$ will be quadrupled, or 40 lbs. per square inch, and the counter-pressure on the 24.8 square inches of P= 992 lbs.

Trebling the normal speed causes a counter-pressure of 9×10 =90 lbs. per square inch in $N\,P$, on 2232 lbs. on P, fully sufficient to balance the loaded elevator.

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SOME PRACTICAL HINTS ON HOW TO TELL A GOOD SURVEYING INSTRUMENT.

BY A. LIETZ, MEMBER TECH. SOC.

Read December 5th, 1890.

Regarding their quality, engineers' instruments may be divided into two classes. In the first category we would place those which are disposed of by their makers directly to the engineer who uses them, while those of the second class are made for the trade and sold principally by dealers. While in most of the latter class many so-called improvements are introduced that make them easily salable, they do not possess the thorough workmanship which makes up a first-class article. There are indeed many improvements, which may yet be added, but if they are not made in a thorough workmanlike manner they are of little, if any, importance, and will in no case make an instrument of fine quality.

Graduation.—In a transit the graduation is the most important part. Solid silver is the best metal known, upon which a perfect graduation can be made, and it is therefore almost exclusively used by makers. It has the advantage of keeping its

surface better than the silver wash, which is found on most of the older instruments.

To examine the graduation, the first thing should be to see whether each line is perfectly sharp and clearly cut; for this purpose it is well to use a compound miscroscope, as only a very keen observer will be able to detect unevenness in the lines with a common magnifier. The starting point of a line, if closely examined, will show whether a perfectly shaped and well-set tool was used in cutting it.

The line shown in figure A, in which the upper or pointed end is the starting point, indicates by its true shape that it could only have been done with a perfect and properly set tool. It is a fact that this shape is found in all graduations of first-class instruments.

A B C

In Fig. B the line has no taper but begins with its full width. In such an event the cut was either made from the inner rim of the circle outward, or what is more likely, the engraving tool was set end for end and drawn from the starting point backwards toward the center. In most cases is the blunt end of the line explained by the latter method. Although the tool used for such a purpose may have been sharp and of the proper form, the additional pressure required to draw it with its wrong end foremost vitiates the degree of accuracy of the graduation, for, if an unnecessary force is applied in producing a line, the tool will not always follow the motion in which it is guided by its drawing mechanism.

Figure C represents a line which was made with an imper-

fect drawing device and a dull tool not capable of doing good work.

It will be noticed in figures A, B, and C, that the starting point of the line shows the shape of the tool with which it was made, and this is therefore the main factor in passing judgment on the value of a graduation.

After we have convinced ourselves that the shape of the line is perfect, we may feel somewhat assured that the graduation is a good one, but if the lines are not equally spaced they are of no value. To determine this is the most difficult as well as the most tedious of tests to be made in the examination of an instrument with graduated circles. The manufacturers have apparatuses with which such examinations can be made in a comparatively short time, and with a great degree of accuracy. No maker of first-class instruments will let one go out of his hands before having convinced himself that the divisions are as perfect as demanded by the character of the article.

The most accurate graduation, however, is of no value without a well fitting center. To prove both several methods are employed. The surest test is to clamp the vernier plate to any point of the circle, then, if by adding the reading of the two verniers together—frequently repeating this manipulation upon different parts of the circle—the sum will always be 180°, they are correct. (This refers to plates graduated from 0 to 180° on both sides of zero; in case of a graduation to 360° a subtraction is required.)

The graduation of an instrument having but one vernier can only be tried with the telescope, which would take several days' time.

It may also be remarked, that short lines on a graduated circle are of some advantage, as the spaces between them appear to be much larger, and there is consequently less fatigue to the eye while reading. It is another fact that during the process of graduating the tool is not required to do as much work, and is therefore apt to keep its fine edges better, thereby securing more perfect work.

The space between the circle and verniers must be very small if an accurate reading is to be obtained; it must appear through

a reading glass like a very fine black and uniform line, and should remain so during the revolution of the circle.

In second-class instruments it is generally found that the verniers and circle are not set in the same plane; this is done to make any unevenness in the plate disappear, but it is a very objectionable feature, for it will cause parallax, and no accurate reading can be taken with such circles.

The Telescope.—The telescope forms a very important part of an instrument and must therefore be closely examined. The reason why so many telescopes of second-class instruments are called good is because they have a very low magnifying power, and consequently will give a good definition, but if the magnifying power of such telescopes were to be increased to what it should be, with the same kind of glasses and workmanship, the definition would be entirely lost. Experience has shown that a telescope of 11½ inches length, such as is generally used in transits of the ordinary size, may have a magnifying power of twenty-four diameters, and will give a good definition and sufficient light, if the new Jena glass is used; while most telescopes of the same size, which I have had occasion to examine, show on an average a magnifying power of fifteen diameters only. It is true that a low power may be of advantage under certain atmospherical conditions, but as a rule a higher power will give better satisfaction if the lenses are first class.

Inverting telescopes, which are used almost exclusively in European countries, are comparatively little in vogue in the American engineering fraternity. They have a great advantage over the erect telescopes; the eye-piece having two lenses only and being shorter, the focal length of the object glass can be increased considerably, aud similarly may the magnifying power be increased without loss of light.

Construction.—In regard to the construction, it appears to be the aim of most makers to build light instruments; but if too much reduced in weight, loss of steadiness will be the result. It is far more advisable for engineers, who want to use light instruments, to place more confidence in smaller sizes, upon which the wind has less resisting surface.

The methods of placing the verniers of transits in such a position that they can be read without stepping aside while observing, has been pronounced objectionable, because the size of the plate level, which is at right angles to the line of collimation, and which is the most important of the two, has to be reduced. The manner in which this can be overcome without reducing its length, or without placing it over one of the verniers (which must affect the degree of accuracy of the reading considerably), and the way in which this level may be set without allowing it to extend beyond the circumference of the plate, I will explain on some other occasion.

The Compass.—The compass should be made as large as possible, but without reducing the value of more important parts. It can often be noticed that instruments with very large compasses have the telescope standards fastened too far from the center, which reduces steadiness; while others, of course still worse, have much spare room between standards and compass box. The point of the center-pin, as well as the upper ends of the needle, must lie in the same plane with the graduation, if the quivering motion which most sensitive needles possess, shall not be noticed on the reading points. As the accuracy depends principally on the pin and cap, these should consist of the best material, while the lift arrangement must be constructed in such a manner as to raise and lower the needle gently, in order to prevent the sudden jerking and falling, which so often is the cause for the rapid wearing out of the point and cap.

It is an important feature of most all of the later instruments that the clamp by which the horizontal circle is held in position works toward the center on a collar, instead of being clamped on the circumference of the plate, and that all tangent screws are provided with opposing springs.

The steadiness of an instrument depends upon its construction; those that have the longest centers, with the shortest distance between the tripod-head and the plates, and in which the distance between the leveling screws is large enough to secure a proper base, or, in other words, a strong foundation, will prove to be firm and steady even in a strong wind.

It is also important that the telescope standards have bases

large enough to secure proper connections with the plate. It is furthermore of great importance to insure steadiness that the lower parts containing the leveling screws be made out of one solid star-shaped casting, instead of the common round plates into which the nuts are simply stuck. There seems to be no other reason for making this latter style than to save a few dollars in labor.

If the star-shaped piece is slotted and provided with clamp screws, lost motion, which is liable to appear in time in the leveling screws, can be taken up.

It goes without saying that all transit instruments should be provided with shifting centers, that ought to be protected by thin metal plate so as to keep the dust out.

The Tripod.—The tripod legs must be light and strong, and of good hard wood, in order to secure steadiness, and should be fitted from the outside, so that any shrinkage of the wood may be drawn up by a nut at any time. In the older style, where the legs fit inside, this can not be accomplished, and in that case it not only reduces the steadiness, but may also lead to serious accidents. The split or skeleton legs are best suited to come up to all the requirements of a good tripod.

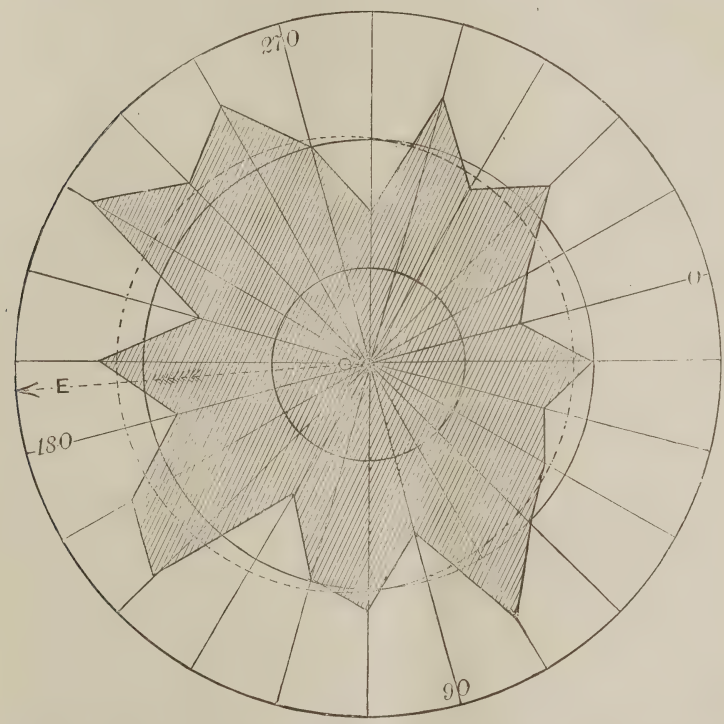
The Case.—The manner in which an instrument is packed in its case is by no means unimportant. A transit must stand upright, so that it can be taken out by holding the lower base-plates and leveling screws, and not the upper plates or the telescope axis. A Y-level box should be provided with an extra space for the telescope to rest in upon its collars.

The Finish.—The outer finish of instruments, although having little to do with their accuracy, will always be found of some elegance in a first class article. Unfortunately most of the second-class possess a brilliant finish that only too often leads purchasers to overlook the more important parts. If engineers when selecting their instruments would thoroughly test the finer qualities, and take into consideration the construction, they would not only be certain to get a more perfect article, but would induce makers to construct and build instruments in accordance with scientific principles.

DISCUSSION.

Mr. Wagoner—The paper is a good practical resumé of the principal points concerning the working qualities of a field instrument, and I presume it refers solely to the selection of a new article.

My experience is that instruments do not often retain the good points shown in the shop after the ordinary usage and almost inevitable rough handling in the field and especially in transportation.



These injuries are usually springing or bending of the centers and eccentricity; that is, the two axes are not co-incident, and the latter condition is one common to nearly all instruments in a greater or less degree. I have seen it large enough to cause an error of three minutes in a right-angle.

As it may be necessary to try to do good work with such an instrument, I will explain my method of examining an instrument having two verniers.

Set one vernier at zero and read the other, calling less then 180° minus and more than 180° plus; take such readings, say every 15° on the circle and tabulate them properly. The mean of all the readings will be the angular difference of the verniers from 180°; subtract this mean quantity from each of the original readings (having due regard to the algebraic signs), and then use the resultant new column, as follows:

With any convenient radius draw a circle on a card board and divide the circle into as many parts as there are observations, numbering the card like the instrument; then using the circle as a base-line, plot the resultant new column, calling inside radical lines *minus* and outside radical lines *plus*, using any convenient scale; join the points thus plotted and cut out with a sharp knife the resultant figure, as shown in the accompanying engraving by shaded lines; balance it over a knife-edge in two or more positions and mark the center of gravity thus found. Replace the figure in the card board and with the original radius and center of gravity as a new center draw a circle. (See figure.) The variations from this new circle are the residual errors due to graduation and observation.

Unless an instrument was either very poor originally or has been very roughly handled, these residuals should not exceed a few seconds.

The center of gravity found by the above method is the vernier-plate axis; its distance from the original center is the amount of eccentricity measured by the scale used for plotting the figure, and a line drawn through the two axes gives its direction.

When the residuals found by this method are small the original data may be plotted to any convenient scale, making the abscissæ 0 to 360°, and the ordinates the observed variation from 180°; with such correction card good results can be quickly obtained.

TECHNICAL SOCIETY OF THE PACIFIC COAST.

INSTITUTED APRIL, 1884.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the statements and opinions advanced in any of its publications.

(VOLUME VII. No. 5.)

ACCUMULATORS AND THEIR APPLICATION.

BY R. B. ELDER, ELECTRICIAN PACIFIC ELECTRICAL STORAGE CO.

Read January 2d, 1891.

It is my wish to engage your attention on the consideration of the practical and every day application of storage batteries, rather than a scientific discussion of their theory.

A resumé of the early history of this discovery and invention, which rivals the telephone in its commercial importance, may not be uninteresting.

At the opening of the present century, in 1801, the French scientist Gautherot noticed that two similar metals, which had been used in the electrolysis of saline water, were capable, immediately after disconnection from the primary battery, of yielding an independent electric current, but in the opposite direction and of short duration.

Interested by this phenomenon, a few experiments were made by Ritter, De La Rive, and a few others, but nothing of any moment was accomplished until the subject was taken up by Gaston Plante, in 1859. The researches of this scientist were remarkably systematic and thorough, as far as they went, although crude as compared with recent laboratory results. He constructed for the purposes of the investigation what was called

a "voltameter" or "voltascope," which consisted of a glass jar holding the solution, and a support for the metal under experiment. In his work he says: "We took care to light it well, and its transparency admitted of perfect observation. All observations were taken under the same conditions by employing wires of one diameter, immersed in the same quantity of liquid, and subjected for the same time to the action of the primary current." Nearly all the metals were tried, and their action, chemically and electrically, carefully studied, with a view to constructing a theory and finding the best metal for a "secondary battery," the name applied in contradistinction to the chemical, or primary battery.

Plante found that the current from a *lead* storage battery was stronger and longer in duration than any of the other metals, and his decision being made he constructed and exhibited his first accumulator before the French Academy of Sciences on March 6th, 1860. This cell consisted of two long sheets of lead, laid one on top of the other, and kept separate by a piece of thick cloth of the same size; the whole was then rolled into the form of a cylinder and immersed in a glass jar containing a dilute solution of water and sulphuric acid. This design of construction he found defective and inconvenient; the cloth separator prevented the free circulation of the solution, or "electrolyte," as we now term it, and in time, rotting, permitted contact between the two plates. This being but one of the many troubles, he altered his cell for a second, and then a third form, which he permanently adopted.

The mechanical construction of the Plante accumulator was but a small factor of total completion, for the work of "forming" the cell, or preparing it for useful service, represented months of care and treatment. When a new cell is connected to a primary battery for "charging" for the first time, the following action can be noticed: the plates are smooth and clean; almost immediately on the passage of the electrical current oxygen appears on the lead plate attached to the positive pole of the primary battery, and this plate being oxidized is covered with a thin layer of peroxide of lead ($Pb\ O_2$). On the other plate the hydrogen reduces the slight layer of oxide which was

formed by exposure to the air, previous to immersion, and then escapes free. If now the charging current be broken and the secondary circuit closed, we obtain a slight current from the lead plates, but of very short duration; in fact, but a spark. The chemical action consisted of the hydrogen, which adhered to the negative plate, reducing the thin layer of oxide on the positive plate, and leaving a thin layer of finely divided lead; and as the reduction was quickly accomplished, the discharge was corresponding.

To increase the discharging capacity of the cell, it is only necessary to increase its capacity for storing oxygen and hydrogen, so to speak.

If we now charge the cell in the opposite direction, *i. e.*, make the plate that was previously positive, now negative, we have the following result: oxygen appears on the now positive plate, which in the first charge was negative, and a layer of lead peroxide ($Pb\ O_2$) formed; on the now negative plate (previously positive), hydrogen is formed, and instead of practically all being set free, some is absorbed in the finely divided lead which was formed by the first discharge. If now we break the charging current, and close the secondary circuit, we obtain a longer and stronger discharge. By continually charging and discharging the accumulator, alternately reversing the polarity of its plates, the storage capacity gradually increases to the desired extent. The cell is then charged and discharged in but one direction; the negative plate consists largely of finely divided lead, and the positive plate of lead peroxide, when in a charged condition. It should be noticed that there is practically no chemical consumption of the elements, no change in their weight, and that charging is the decomposition of water, and the oxidation of the positive plate, while discharging is synthetical, forming water, and reducing the peroxide.

Plante, after the completion of his work, had at best but a laboratory demonstration, and an apparatus of practically no commercial value. It is true that some were used for galvanocaustic purposes, firing mines, time signalling; but the many defects which arose, and their great deterioration, taken into consideration with the immense labor of manufacture, precluded any extensive commercial use.

The weight of his cells, for a given output, was considerable; the peroxide very shortly scaled off, owing to the necessity for frequent reversals in forming the cells, by the time complete development was reached the plates were rotten; more especially the positive, which became much more fragile than the negative, as in this plate the chief wear took place.

About the year 1878—eighteen years after Plante produced his first accumulator—the French chemist-electrician, Camille A. Faure, made his great invention, and produced what promised to be a commercially successful accumulator. This was eagerly welcomed by the public, for the dynamo about this time came into very general use, and the need of an "electrical reservoir" was urgently felt. *Faure conceived the idea of mechanically applying the lead oxide or active material to the lead supports.* His original cell consisted of two lead plates covered with a paste of red lead and sulphuric acid, mixed to a doughy consistency; the whole was then rolled together, being kept separate by a piece of cloth. This pile was then immersed in the electrolyte and subjected to a primary current, which converted the red lead or lead oxide on the positive plate to lead peroxide, and reduced the red lead on the negative plate to spongy lead. Thus Faure had made it possible to "form" an accumulator in a few days rather than months; the capacity of the cells was greatly increased over the Plante cell, as a much greater quantity of active material could be applied mechanically than electrically; also the weight of the cell was greatly reduced for a given output. The invention was patented, the first claim being for an electrode consisting of a support, coated with an active layer of absorptive substances, so as to instantly become spongy, and thus capable of receiving and discharging electricity. This claim is the foundation of any successful accumulator. A company was formed in Paris for the purposes of manufacture, and tons of these storage batteries were put on the market for commercial uses. Thousands of dollars were expended before the many defects, both electrically and in mechanical design, were discovered, and it was sorely brought home to the originators of the industry, as Dr. Lodge put it: "that because it can be shown that a thing will be extremely useful when perfect, it

does not follow that it has already attained perfection; historical developments are enormously against such abnormal and instantaneous maturity."

The immature forcing of the accumulator into prominence, and the unfounded claims made for it, caused the loss of public confidence, which has, however, been regained by repeated and successful demonstrations;

The defects of the Faure accumulator were most noticeable in the peeling off of the active material, and the rotting of the cloth separator, which gave rise to many other faults.

Meanwhile, other inventors entered the field of improvement, chiefly with a view of constructing a suitable support for the active material which would prevent scaling. Mr. Sellon, of London, produced a lead grid, the interstices of which were to be filled with the active material, and this design proved to be most successful. About this time—in 1881—the Electrical Power Storage Company, Limited, was formed in London by Sir William Thomson, William H. Preese, and associates. This company bought the patent rights of Sellon, Volchmar, Swan, and a few others, which covered all the essential improvements on the original Faure cell. Subsequently this corporation absorbed the Faure patents for England, and began to manufacture what is to-day known to the world as the "E. P. S. accumulator."

In 1882 The Electrical Accumulator Company was formed in New York, controlling the American patents of the E. P. S. Co. of London, and a large factory was erected at Newark, New Jersey.

Improvements have been made continually, on both sides of the Atlantic, and to-day we are turning out an accumulator which is practical and successful from every standpoint, as we are now demonstrating.

Without tracing the gradual but marked development of the battery, from 1880 to 1890, I propose to conduct you through our factory, and follow the manufacture of a cell.

The foundation of a "Pile," as the assembled lead plates are called, is the lead grid. The pig lead is brought to the door of the foundry, and melted in large iron pots, the temperature being kept barely at red heat. The iron moulds or "chills," for

the casting, weigh, with their supports, some two hundred pounds, whilst the cast grid weighs but two pounds; this is to prevent the too sudden cooling of the castings. Great care is necessary in the casting of the grids that they contain no flaws, or air-bubbles, and are of uniform strength. This is extremely essential in a perfect cell, for the reason that the paste expands during oxidation, and unless this expansion is even, and does not subject the frame-work to an unequal strain, warping of the plates or "buckling," is apt to ensue. It is a noticeable fact, that buckling from chemical action is confined to positive plates, the negative being distorted usually only by mechanical pressure from the positives.

The chill is carefully cleaned, heated to a proper temperature, and the molten lead poured from a dipper.

There is now being prepared a new form of furnace, whereby the heat will be subjected to very accurate regulation, and from which the lead will be conveyed to the chills by means of a pipe and faucet.

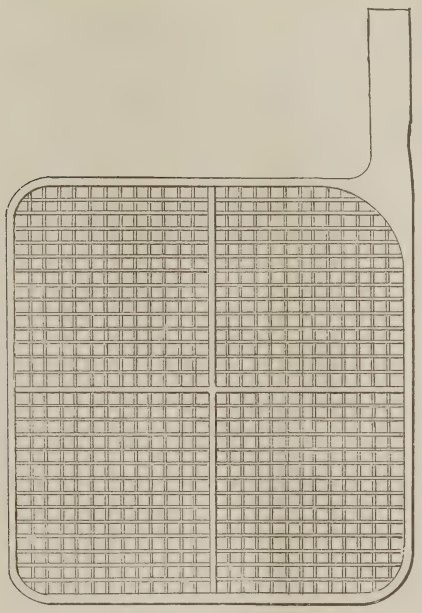
The grids, when cold, are dressed free from projections and gates by electric shears, and are then packed in the store room for future use, in the pasting department.

For a time it was thought it would be beneficial to stiffen the grid by bars, or cast it from an alloy of lead and antimony, but from experiments deductions were drawn, that a grid of uniform strength and *soft* metal, such as lead, was preferable.

You will please notice the character of the interstices in this grid which I hold: they are in the form of two pyramids, inverted, apex to apex, and the bases on either side of the plate—this serves the double purpose of keying the paste, and giving greater chance for expansion without straining any part of the grid support. Every grid is provided with a projection, called a "lug," to carry the current. In the 15 L type cells, the grids are 9 inches wide by $9\frac{3}{4}$ inches high, by 3-16 inches thick, approximately, and contain about 1,000 interstices.

We will now proceed to the pasting room. In the manufacture of the first accumulators, both the negative and positive plates were pasted with red lead ($Pb_3 O_4$). In forming, the positive paste is reduced to lead peroxide ($Pb O_2$) and the negative

paste to spongy lead, requiring about two weeks of steady treatment, under the electric current to reduce the red lead ($Pb_3 O_4$), to spongy condition (Pb.) It was conceived that the negatives could be pasted with a lower oxide, and hence the time necessary for forming reduced; we now use for the negative paste, litharge, (PbO).



Lead Grid

The oxides are mixed with dilute sulphuric acid, to a consistency of stiff dough; the lead grid is laid on a marble slab and the paste evenly pressed into the interstices by a hard wood "spatula," manipulated by hand. Hitherto, machinery has not been devised to successfully paste the plates.

Great care is exercised in the selection of the oxides, and every load is chemically analyzed, as on their quality, to a great extent, depends the future of the cell.

From the pasting department, the plates are carted to the drying room, where they are subjected to a temperature kept evenly at 100° Fahrenheit. The object of this is to harden and

set the paste. When thoroughly dried the next process is in the "forming" department. This treatment, as I have explained, is for the purpose of reducing the oxides, and may be termed but a lengthy charge. The boxes in which this forming is conducted are each 14 inches long, by 10½ inches wide, by 12 inches deep, inside measurements. They are very strongly made and lined with sheet lead, the seams being burned; the capacity of each box at one time is 16 plates.

The method and time of forming the positive and negative plates respectively have been frequently modified, and I make the following statements in this particular subject to correction:

To form the positive plates, *i. e.*, convert the red lead ($Pb_3 O_4$) to lead peroxide ($Pb O_2$) requires a current of 0.028 amperes per square inch, flowing for 48 hours. This constitutes but 80 per cent. of a complete formation, the remaining 20 per cent. being effected when the battery has been installed for regular duty. This forming by installments is done to facilitate transportation of the accumulators, as the positives carry much better in this incomplete condition.

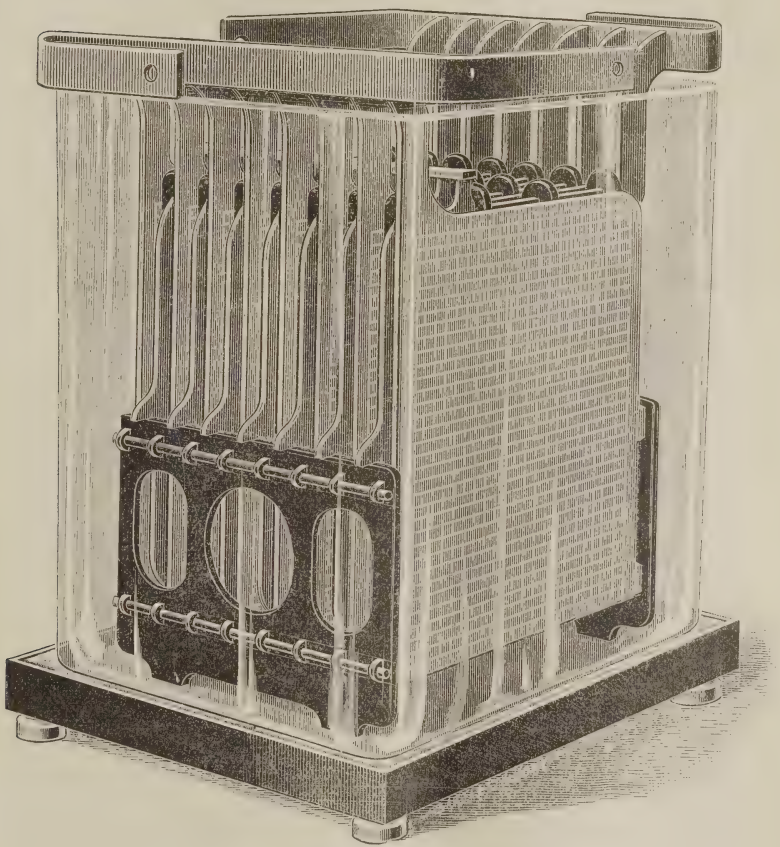
To form the negatives requires a current of 0.023 amperes per square inch, for five consecutive days of 24 hours each. It is this very appreciable difference in time that necessitates the separate treatment of positives and negatives.

But to return to the forming boxes—alternating with the plates to be formed are placed "blind grids," or dummies, which act either as positives or negatives according to the polarity of their opposites. After being thusly "packed" in the forming boxes the plates are electrically connected by a No. 8 copper wire bound to the projecting lugs. A battery of sixty of these packed boxes is assembled and connected to a generator, through the proper instruments, for carefully measuring the current.

From an elevated tank the solution, or "electrolyte" for the plates, is drawn off through lead pipes; this electrolyte is dilute sulphuric acid, and water of specific gravity of 1.160. During the forming it is aimed never to shut down the current, and great care and nicety are observed in putting through the proper quantity. When all is completed the electrolyte is drawn off by gravity through lead pipes into a receiving tank, and, after

being fortified by commercial acid to make up for that absorbed, it is drawn up by a steam syphon into the elevated tank for use in the next forming.

The formed plates are washed in clean water, carefully examined for any defects, and then passed to the finishing room for assembling.



"15 L" Cell.

The dimensions and descriptions heretofore given have been of our 15 L type cell, which is the largest made and the one most generally adopted. For the negative element, 8 plates are

clamped in position, and to the projecting lugs is burned a long lead strip called the common negative lug; there is also a second strip burned to the bodies of the plates for the purpose of increasing their rigidity and conductivity. For the positive element, 7 plates are likewise burned together.

In the cells first manufactured there were just as many positive plates as negatives, but this gave rise to "buckling," or warping of the extreme positive, for the reason that the chemical action on both sides was not equal, and resulted in uneven expansion; this was remedied by the addition of one more negative.

For the purpose of burning the numerous joints about a cell, air and hydrogen under pressure are used making a fine pencil of flame, an inch or two long, and about $\frac{1}{8}$ inch thick. The negative element is braced and supported on both sides by hard rubber bridges, and stands as you see it; a positive element is set inside, a negative plate alternating with every positive, and being kept separate, electrically, by these four rows of hard rubber pins. This constitutes the "pile," as we term it, complete. From this mechanical construction, repairs and renewals are most readily effected.

The piles are now placed in strong pasteboard boxes, which, in turn, are packed with excelsior, each in a heavy wooden case, and stored in a room protected from extremes of heat and cold, and from which they are shipped in closed cars as required.

The containing jars are made either of glass or hard rubber, for stationary or portable purposes respectively.

There are now manufactured five sizes of accumulators, which are known as the 15 L, 23 M, 15 M, 7 M, and 5 S; L being the abbreviation for large, M for medium, and S for small sized plates; the figures designate the number of plates in a cell.

To give an idea of the relative storage capacity of the different types, at normal rate of discharge, the 15 L cell, weighing 130 pounds all complete, will yield electrical energy the equivalent of a little over 2.25 H. P. for a period of ten consecutive hours, equal to $\frac{4}{5}$ H. P. hours; the 23 M, weighing 40 pounds, will discharge the equivalent of 0.067 H. P. for six consecutive hours, equal to 0.402 H. P. hours; the 15 M, weighing 25 pounds, will discharge 0.04 H. P. for $6\frac{2}{3}$ hours; the 7 M, weigh-

ing 15 pounds, will yield 0.016 H. P. for $6\frac{2}{3}$ hours, and the 5 S, weighing $2\frac{7}{8}$ pounds, .0053 H. P. for 4 hours.

Work is a multiple of two factors, viz., pressure and quantity; the electrical unit of work is the watt; of pressure, the volt; and of quantity, the coulomb. The coulomb is that quantity of current having a cross-section, as it were, of one ampere flowing for one second.

A watt, of course, is equal to one ampere, multiplied by one volt. We speak of a stream of water, flowing from a pipe, at x cubic feet per minute or second, at y pounds pressure; using this convenient analogy, and imagining the stream of water to be a current of electricity, we would say the current strength or quantity was x amperes, at a pressure, or potential, of y volts, and the work, or watts, would be represented by (xy).

Each cell, in fair condition, when charged, has a normal effective pressure of two volts, and its quantity, or ampere output is directly proportional to the number and size of the plates. The normal discharging currents of the 15 L, 23 M, 15 M, 7 M, and 5 S cells, respectively, are 30, 25, 15, 6 and 2 amperes. these figures are approximately 80 per cent. of the maximum discharging current allowed by the manufacturers.

The cells can be discharged at a rate *greatly* in excess of even the maximum rate, but only at the expense of their efficiency and life.

One of the features of the Faure accumulator, eminently necessary in actual use, is the fact that they maintain nearly a constant pressure or potential, from the beginning to the end of discharge. The pressure curve is an almost horizontal line, until it drops very abruptly, at the end of discharge. In a primary cell the fall is steady and gradual.

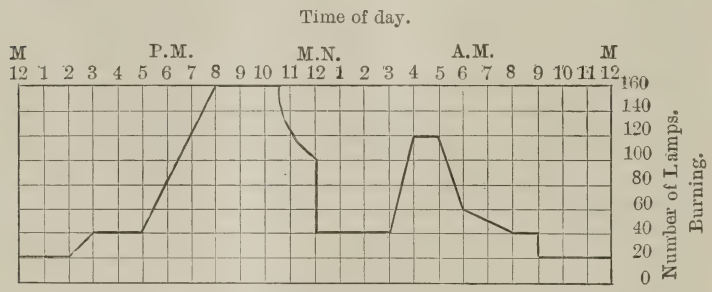
This is a brief outline of the evolution of the accumulator of to-day; ten years have marked the development from the crude application by Faure of his invention to the perfected apparatus, which is as necessary to the electrical industries of to-day as the gasometer to a gas plant.

In the application of accumulators to the various industries, and as adjuncts to lighting plants, many obstacles of regulation were encountered, and the field of advancement in this

direction promised to be no smaller than that of the accumulator itself. As you will soon perceive a battery, without regulating apparatus, is useless.

A description of the installation and operation of an accumulator plant for lighting, or power purposes, will give a fair idea of the method of application.

The first consideration is the necessary, or most economical ratio of capacity, between the dynamo machine and storage battery. A parallelogram of the 24 hours is laid out, and on it we plot the light curve of the building or institution to be illuminated. For example, I have plotted an imaginary case on the board:



Light Curve For 24 Hours.

From this we see that the greatest number of lights burned at any one time is 160, and that the heaviest load comes between 6 P. M. and 12 midnight. As there is always loss in conversion of power or current, it is most economical to operate the engine and dynamo when most lights are being burned. To operate a 160 light dynamo will require an engine developing 16 mechanical H. P. It is an established fact that an engine and dynamo are running most economically when at full load, *i. e.*, the cost per light in fuel is least when 160 lamps are burning and considerably greater when but one is burning; this is not considering the constant expenses of labor, taxes, interest, etc. In many direct lighting plants that which is made or saved before 12 o'clock midnight when the load is heavy is lost after 12, owing to the necessity of running to supply what few lights may be needed. Therefore we wish to operate the engine at such a time as the load is full and constant.

Calculating from the curve the total consumption of light in the 24 hours is 1,692 lamp hours; of these 610 are burned between the hours of 12 midnight and 12 noon, and the balance 1,082 during the remaining hours. If the dynamo be operated at full load, 160 lamps, from 12 o'clock noon to 12 midnight, the total energy generated will be equal to 1,920 lamp hours; of this number 1,082 will be burned direct, leaving a surplus for "storage" of 838 lamp hours. The manufacturers guarantee that a battery properly cared for will return 80 per cent. of the current put in, and after allowing this 20 per cent. loss by conversion, there is an available 670 lamp hours which can be reclaimed from the battery; as there will be required but 610 lamp hours, a surplus remains for emergencies of 60 lamp hours.

As stated, during the 12 hours run, the dynamo will generate the current equivalent of 1,920 lamp hours; the plotted curve shows that there will have been used 1,692 lamp hours, and adding to this the 60 lamp hours surplus the available, or reclaimable output, is 1,752 lamp hours for 1,920 generated, hence the loss by conversion is 168 lamp hours, or $8\frac{3}{4}$ per cent.

The monthly expenses of operation, in fulfillment of the above conditions, will be approximately as follows:

Engineer	$ 90 00
Fuel, at $8 per ton	115 20
Lamp renewals, at 44 cents	22 33
Water, oil, waste, etc	18 00
Depreciation of plant, at 10 per cent. on its entire first cost	58 32
Interest on investment, at 6 per cent	35 00
Total	$338 85

Fuel is calculated at four pounds per horse power hour, and an additional allowance of 20 per cent. for getting up steam.

From these figures we can ascertain two facts, viz: Will it pay to put in the plant? And if so, will it pay to install accumulators in addition?

As stated there will be consumed, or are now, 1,752 lamp hours daily, or 52,560 lamp hours per month of thirty days. A

gas jet giving 16 candle power consumes at least 6 cubic feet per hour, therefore the equivalent of 52,260 C. P. in cubic feet of gas is 315,360, which, at $2 per M feet, amounts to $630.72 per month.

It will cost, as shown, to operate the accumulator plant, $338.85, and the net saving over gas will amount to $291.87.

It will pay to install the plant. As to the installation of accumulators, in addition to the dynamo, is it, or not, a business proposition?

Let us estimate the cost of operating the plant all 24 hours without accumulators, granting that it is practical, no breakdowns occurring or other interferences arising:

Two engineers	$180 00
Fuel, at $8 per ton	151 77
Lamp renewals, at 44 cents	22 33
Water, oil and waste	25 00
Depreciation of plant, at 10 per cent	25 00
Interest on investment, at 6 per cent	15 00
Total	$419 10

I arrive at the coal consumption, as follows:

The total light consumed is 1,752 lamp hours daily, or an average of 73 per hour, and allowing that the efficiency would be the same as a full load, the power required is 7.3 H. P. per hour, at four pounds per H. P. hour, and allowing as before an additional 20 per cent. for getting up steam, there would be consumed 13.28 tons per month, which at $8, amounts to $106.24; this is granting that the efficiency of the steam plant on 15 per cent. load is as high as at full load—which is impossible. I estimate that the efficiency suffers likely by 30 per cent., and the coal consumption would, at least calculation, amount to $151.77 per month. If you recollect, the operation of the accumulator plant cost (estimated) $338.85, and even on this basis—a practically impossible one, for no machinery can be operated twenty-four hours daily, without rest or breakdown—the operation of a direct plant, under the same conditions, would cost (estimated) $80.25 more.

There remains a third question to settle: Would it be cheaper to put in a direct plant, operate it between the hours of 6 P. M. and 12 midnight, and during the balance of the twenty-four hours use gas? We estimate that the cost of operating the plant for six hours, is as follows:

Engineer	$90 00
Fuel, at $8 per ton	69 12
Lamp renewals	11 37
Water, oil and waste	12 00
Depreciation of plant, at 10 per cent	25 00
Interest on investment, at 6 per cent	15 00
Total	$222 49

During this time we have supplied 862 lamp hours, which leaves 890 to be supplied by gas, which would consume, at six cubic feet per lamp hour, or 5,340 cubic feet per day, equal to 160,200 cubic feet per month of thirty days, which, at $2 per M feet, amounts to $320.40 per month. Add to this the cost of operating the electric plant, and the total cost of the illumination amounts to $542 89.

Concentrating our figures, a summary shows:

The cost of illuminating by gas alone	$630 72
" " " " direct plant	419 10
" " " " electricity and gas combined	542 89
" " " " accumulators	338 85

Deduction: Accumulators are eminently the proper method in this case.

The proposition on which I have estimated, is by no means an exceptional case, but of course the calculations are but approximate.

There are truly instances in which the accumulator would be of little use as an economizer, but *none* where it would be a superfluity.

On a certain class of large installations, it pays to install duplicate electric plants, and work two or three gangs of men, but even here the accumulator has its work.

If the ampere meter, indicating the current output, be noticed

during the run, the readings will vary and fluctuate, and if from these readings a load curve be plotted, it will be found to generally contain "hollows," representing the turning on or off of lamps. These hollows represent an actual loss of fuel, unless they extend over a period of long duration, for no firing can be so closely regulated as to save the fuel which they represent. If accumulators be included in the installation, these otherwise lost hollows are saved, and 80 per cent. returned for useful work.

But to resume the installation of our plant. The capacity of dynamo and battery having been determined upon, a place is selected, guarded from excessive moisture, and from heat or cold, and here shelving or tables to support the battery are erected; care is taken to have strength, and the shelves so supported as to be dependent upon screws or nails as little as possible, thus guarding against a breakdown by reason of corrosion from the acid spray. If expense be no consideration, all the woodwork is covered with beaten lead, but usually the shelving is painted with P. & B. compound, or asphaltum varnish, both of which are excellent protectors.

The cells are now unpacked, and carefully cleansed from dust and excelsior; the rubber pins are straightened, so as to avoid uneven pressure; the lugs are brightly scraped, and the pile placed in the glass jar. The jar is placed on an insulating tray, sawdust being used for obtaining an even and yielding seat, and also serves the purpose of an absorbent for the drippings. This insulating tray is for the purpose of preventing electrical leakage through moisture.

When all are in position, the lugs are joined by brass bolts, and the whole connection painted with melted paraffin wax, to prevent corrosion. The cells are connected, of course positive to negative, leaving one free positive and one free negative. The switch-board for the controlling instruments is placed near the dynamo, as but little attention is required anywhere else, the battery being connected to the switch-board by wire cables.

It is always preferable to use what is called a "shunt wound" dynamo, which is a type not subject to reversals of polarity—a sorry disaster for the battery and also machine. Its voltage, or

potential, must be in excess of that of the battery, otherwise there will be a back flow of current.

The positive pole of the dynamo is connected to the positive of the battery, and likewise the two negatives. If now the plant be started running and a belt flies off or steam goes down, or if, for any reason, the voltage of the dynamo falls below that of the battery, there will be a back discharge and waste of current around the dynamo, which, in some cases, might result seriously to the machine. To prevent this there has been devised an automatic break-switch, which opens the circuit whenever necessary.

As already stated, there is a rate above which the cells should not be allowed to discharge, and to prevent too heavy a current being forced in or drawn out we have an automatic overload switch, which, at the proper moment, opens the circuit and introduces resistance, thus checking the flow. The current from the dynamo flows through an ampere-meter, which indicates the total current generated. In circuit with the battery is an ampere-meter, which indicates whether the current is flowing in or out of the battery, and how much. If there are lamps being burned at the time of charging, by subtracting the current taken by the battery from the total amount generated, the remainder is the current absorbed by the lamps. A volt-meter or pressure indicator is arranged so as to permit of readings being taken from the dynamo, battery, or lamp circuit, this being a guide as to the proper incandescence of the lamps.

As has been stated, to permit of a current being forced through the battery, it is necessary to keep the pressure of the charging dynamo in excess of the normal pressure of the battery; this normal pressure is the point at which the lamps should be burned, as any raise in the voltage is greatly sacrificial of their life, increasing approximately as the cube of the excess; therefore, to burn lamps and charge the battery at the same time, it is essential to have means of absorbing this excess, and this is done by means of "Counter Electromotive Force Cells"—meaning counter-pressure cells. These cells are made of an alloy less oxidizable than lead, and have no paste, the interstices being vacant; in other respects they resemble the accumulator of the

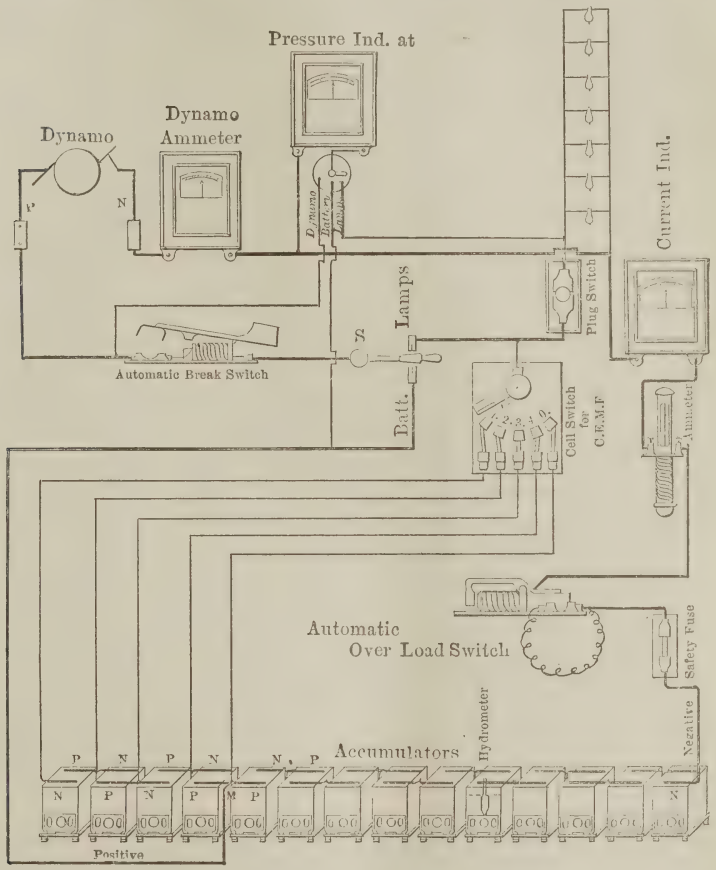
same type. When a current is passed, they immediately offer a counter-pressure of two volts; their storage capacity is nil. These cells are so connected that they can be thrown in or out of the lamp circuit, one at a time, until the lamp pressure is correct, by means of a 5-point cell switch. The original method of government was to cut in or out some cells of the battery, the result being that these particular cells were not charged and discharged to the same extent as the remainder, which gave rise to several faults, which are overcome by this later plan.

All the main wires, as is usual in all electrical installations, are protected by safety fuses; these are made of an alloy which fuses at a certain temperature. The strips are so proportioned as to carry the proper current for its particular wire, and if from any accident the quantity should be increased, the fuse will "blow," open the circuit and prevent undue or dangerous heating of the circuit. All instruments are on slate or porcelain bases, thereby admitting of no absorption of moisture, warping, or burning. The connections of the switch-board completed, are shown on the board. Those named are but a few of the many instruments devised for different applications, such as charging from arc circuits, etc.

The construction work all completed, and steam up, we are ready for the first charge, which requires twice the time of any subsequent charge, as it is necessary, if you remember, to complete the forming of the positive plates. The electrolyte has been mixed to a specific gravity of 1.160, and is perfectly cool. Each cell is partly filled so as to cover the plates about one inch, and on testing with the volt-meter, the indication is about 70 per cent. of the normal. This current we throw into the fields of the shunt dynamo, and correctly polarize them for our purpose. The machine is started, and when the potential is just above that of the battery, the circuit is closed and a light current sent through the battery. The cells are now completely filled, the current being on all the while—the object of this is to prevent injurious sulphating starting in, which occurs when they are left standing in the electrolyte in a discharged condition.

A current averaging about 28 amperes is put through the battery

for nearly 27 hours, equal to 750 ampere hours, the regular charge being 375 ampere hours. The paste in the negative plate is reduced from litharge (Pb O) to spongy lead (Pb), and the positive



Plan of connections in an ordinary Accumulator Installation.

The Pacific Electrical Storage Co.

from red lead ($Pb_3 O_4$) to lead peroxide ($Pb O_2$). In three charges the battery develops its regular working state, and the time of charging from then on depends on the previous discharge. The

state of charge is indicated by the specific gravity of the electrolyte as shown by a graduated hydrometer, the specific gravity of the liquid falling as the cell is discharged, and rising as it is charged. A complete charge is indicated by the electro motive force of the battery, effervescence of the electrolyte, and the maximum specific gravity.

An accumulator in a lighting plant has other advantages than merely an economizer. In direct lighting it is essential that there be used none but the best automatic engines, for irregularity of speed is fatal to a steady light, and if the load be fluctuating, constant attention is necessary at the dynamo.

By the use of a storage battery this serious difficulty is overcome, and an absolutely steady and constant light is available when charging and burning direct, even with the most unsteady power; this fact is eminently demonstrated in the use of gas engines for charging purposes. Any hollows in the electro motive force of the dynamo are instantly filled in by the back pressure from the battery—this is noticeable in the deflections of the ameters—that of the battery immediately following. The deterioration of a battery is a matter of considerable interest.

Certain parts, of course, are not depreciable, such as the jar, insulating tray, etc.; the chief wear comes on the positive plate, and very little on the negative, as the hydrogen is occluded mechanically, so to speak. The positives, at the end of their life, become worn and rotten, the lead grid having been oxidized; under proper usage they should last from three to five years. In fact, the rate of deterioration has been so determined, that the manufacturers are willing to supply all renewal plates, indefinitely, for a certain percentage per annum, depending on the work habitually required.

The E. P. S. Co. of London, during the year 1888, installed a 10,000 light accumulator station at Chelsea, England, and from their report, published in the *English Electrical Review*, February 21, 1890, I make the following extracts:

"I would point out that one of the advantages of the system adopted at Chelsea is, that it lends itself readily to gradual increase of plant, according to the necessarily gradual increase in the demand, and does not necessitate at starting the large ex-

penditure of capital on buildings and heavy machinery, as with direct running systems, in which a long time may elapse before sufficient work can be found to fully employ the plant. All the electricity which has been produced has been supplied to the consumer direct from the E. P. S. storage batteries.

"The consumer is never, under any circumstances, in connection with the charging current, and therefore he is not subject to the disagreeable pulsation and inequality in the light often noticeable when it is produced direct from running machinery. Nor is he in any way liable to the inconvenience of sudden total extinction of his light from difficulties or mishaps with boilers, engines or dynamos. It is an interesting fact that upon the E. P. S. system, when the batteries are being charged, the engines and dynamo-electric machinery are always operating under the conditions of highest efficiency and maximum output. This is proved in practice by the small consumption of coal, which, for every Board of Trade unit actually supplied to the consumer's lamps, has an average of about eleven pounds. You will be gratified to learn that little or no symptoms of wear are discoverable, even on those E. P. S. batteries that have been longest in use; and in no case has a single plate had to be renewed.

"I wish to call particular attention to this question of depreciation of accumulators, because it is one of the main points urged against their adoption. I have always contended that in practice it would be found that when storage batteries were installed in central stations (where one man can look after several hundred cells with as much ease as he can look after a few in a private installation) that better results would be obtained than had almost ever been got before, and experience is now showing this to be a fact. The batteries in this station are all in glass cells, and you can therefore judge for yourselves what excellent condition they are all in; but a still stronger answer is found in the fact that the manufacturers are prepared to supply all the necessary material for the renewal of any plates or portion of the battery that require renewing, at the annual rate of 12 per cent.; but here at Chelsea, where we have engineers who are well acquainted with E. P. S. storage batteries, we have declined

this offer of the manufacturers, because we prefer to be our own insurers, as we know it will cost us less than that."

The many and varied uses to which accumulators are being put, would require a volume for enumeration.

In marine work the field is large, and considerable has been accomplished, especially in the propulsion of small launches and torpedo boats. There are some twenty or more storage battery pleasure boats on the Thames, England, which are rented out by the day. This is an immense improvement over steam and gasoline launches, and is fully appreciated by luxurious pleasure-seekers, when they notice the absence of soot, smoke, odors, noise, and cramped quarters. The battery is placed under the floor of the boat, and also serves the purpose of ballast. On the Atlantic shore there is an accumulator launch, *The Magnet*, of which we have particulars. She is 28 feet long, with 6 feet beam, and 3 feet depth amidships, and draws 30 inches of water at the stern. The motive power consists of 56 cells of our 23 M type accumulator, and one Reckenzaum motor, situated in the stern, and coupled directly to the shaft. The manipulation of but two switches gives perfect control for starting, stopping, and reversing.

The total weight of battery, motor, shaft, screw, etc., is 3,000 pounds, which is about equal to boiler, engine, ballast, fuel, etc., for a steamboat of the same size. The speed of the boat is from six to eight miles an hour, and on one charge she will run about 80 miles; 2½ electrical H. P. are developed.

Such launches as this might be very effective in the Custom House service for patrol work; to illustrate their noiseless motion, Prof. Anthony Reckenzaum caught a sleeping sea-bird in the English Channel.

The battery has also been applied in propelling dog-carts, tricycles, etc., but this is hardly practical for everyday use.

Yacht lighting has been very satisfactorily accomplished, the charging usually being done from a dynamo on shore.

The accumulator is the solution of the train-lighting problem.

It is granted that primary cells are out of the question, and there remains but two methods—the accumulator and the direct system. For direct lighting, the dynamo is placed in the baggage car, and is driven by a small engine fed from the locomotive boiler; the cars are connected to the dynamo by means of wires. The most serious objection to this method is, that detached coaches are in darkness.

In the storage system, the battery is placed under the body of the coach, and removed for charging when necessary.

The storage battery has made a radical innovation in the dental and medical professions, and the use of the primary cell is fast disappearing.

Small power users of all classes most appreciate the phrase, "Light and power on tap."

The latest development of the usefulness of the accumulator system, and one which promises to exceed any of the others in its commercial importance, is storage battery street car traction. Its advantages over all other modes of street railway operation and particularly of the overhead electric and cable systems are both numerous and apparent:

1st.—The cost of construction is considerably less.

2d.—Each car is an individual motor, and independent of every other one.

3d.—In case of an accident to the steam plant, the whole road is not immediately stopped.

4th.—The thoroughfares are not marred by the poles and overhead conductors.

Gentlemen—The importance of the subject, and my desire to touch upon as many points as possible, must be my apology for the length of my paper, and for the meagre manner in which, of necessity, I had to handle the details, which I trust you have found not altogether uninteresting or uninstructive.

Upon your adjournment the Pacific Electrical Storage Company cordially invites you to visit Swain's Bakery, on Sutter

street, and there inspect an accumulator plant that has been in actual operation, 24 hours per day, for the past year without repairs or renewals of any sort.

R. B. ELDER, Electrician,

Pacific Electrical Storage Company, 220 Sutter street,
San Francisco, Cal.

January 2, 1891.

TECHNICAL SOCIETY OF THE PACIFIC COAST.

INSTITUTED APRIL, 1884.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the statements and opinions advanced in any of its publications.

(VOLUME VII. No. 5.)

NOTES ON THE BEHAVIOR OF STEEL RODS AT THE ELASTIC LIMIT.

BY LUTHER WAGONER, Mem. Tech. Soc.

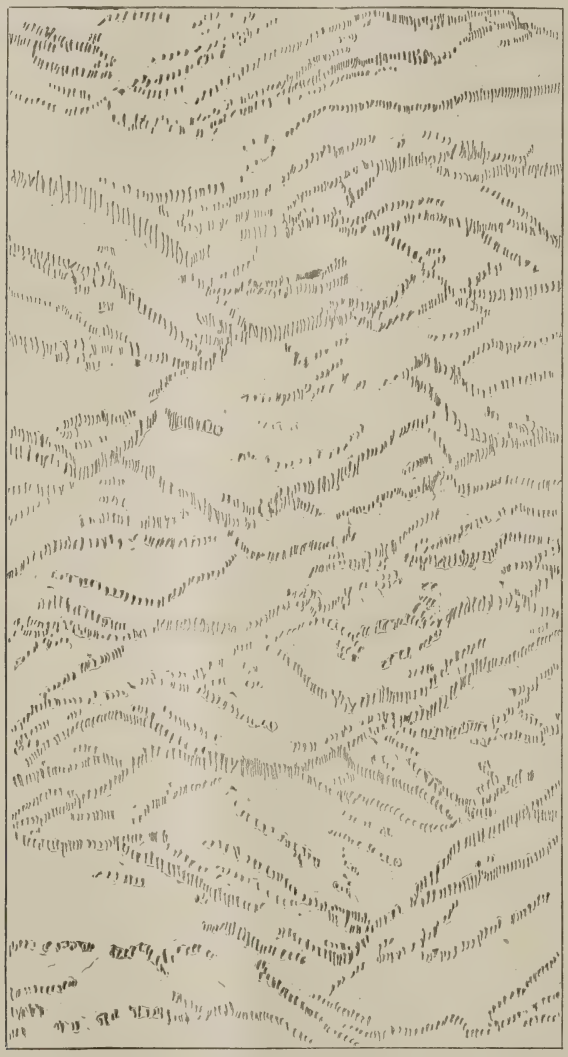
[Read at the April Meeting, 1890.]

In the transactions of the American Society of Civil Engineers, Vol. 3, is an account by Louis Nickerson of the examination of glass beams and rods under stress, by the use of polarized light. The principal fact shown in these experiments is, that the beams or rods are apparently not under uniform stress. In the case of glass rods or columns under stress, certain dark bands, normal to the direction of the force applied, were observed, whose interval of spacing varied with the load.

Mr. Nickerson's idea was that the dark bands were lines of no molecular disturbance, but no theory was presented as to their probable cause.

Having witnessed these experiments, the writer thought a possible explanation of the black bands might be due to interference of wave action; thus, if the present notion of molecular arrangement be correct (*i. e.*, stresses are transmitted by wave action), there might exist nodal points in a rod under stress, where the stresses by interference would be neutralized, and in consequence there would be no change in the diameter. Hence, if a carefully turned and polished metal rod be pulled to a point slightly below the elastic limit, its surface should present

a corrugated appearance; and if pulled to a point slightly above the elastic limit, the flow should take place between the nodes, leaving the latter unchanged in diameter.



Appearance of the surface of a steel bar after stretching.

To test the matter, Lieutenant-Commander F. P. Gilmore, U. S. Navy, had prepared a number of rods of rivet steel (open hearth); the rods were twenty inches long, and turned and polished for a length of twelve inches, the diameters of the turned part ranging from five-eighths to one inch.

The rods had an average breaking strength of 55,000 pounds per square inch, and the elastic limit was about 35,000 pounds per square inch. They were pulled in the testing machine at the Union Iron Works.

When nearing the elastic limit a slight difference of diameter could be felt, but this disappeared when the stress was reduced; at the moment of reaching the elastic limit the line of light reflected from the polished surface, which had been narrow and straight, suddenly became irregular and rather sinuous, the corrugations upon the surface being apparent to the touch. To develop these corrugations so that they would be visible at all points upon the surface, the rods were "honed," by carefully drawing a flat hone $1\frac{1}{2}$ inches wide along the bar, thus touching all the high points and leaving the surface in a condition to be easily observed.

The accompanying engraving is an accurate development of the surface of one of the rods, for a longitudinal distance of 5.5 inches, the diameter of which was 0.93 inch; the lines in this drawing are the scratches or marks made by the hone, and also the high or unaltered parts of the rod where there was little or no flow of metal.

Although somewhat irregular, it will be noticed that there is a general parallelism of the principal lines, and some degree of uniformity of spacing between them, perhaps as close as could be expected from an unannealed rod not perfectly homogeneous.

From the experiments made there is ground for the belief that *homogeneity of the metal will be indicated by the regularity of the lines thus obtained*, as the rods can be honed without removing from the testing machine; the method can be easily applied before testing to destruction, and in this way perhaps an additional test for QUALITY OF MATERIAL may be had.

Additional experiments upon carefully annealed bars appear desirable.

TECHNICAL SOCIETY OF THE PACIFIC COAST.

SAN FRANCISCO, CALIFORNIA.

INSTITUTED APRIL, 1884.

PROCEEDINGS.

NOTE.—This Society is not responsible, as a body, for the statements and opinions advanced in any of its publications.

(VOLUME VII. No. 5.)

REGULAR MEETING.

September 5, 1890.

Called to order at 8:30 P. M. by President John Richards.

The minutes of the last regular meeting were read and approved.

The following gentlemen were duly elected to membership in the Society:

Members—Harold T. Power, Mining Engineer; Charles J. Koefoed, Mechanical Engineer; C. I. Hall, Mechanical Engineer; James C. Gilfillan, Mechanical Engineer; B. McIntire, Mechanical Engineer; Fred. Orton, Mechanical Engineer.

Junior—Robert Edwin Bush, Graduate College of Engineering, University of California.

The following propositions for membership were announced, and disposed of in the usual way:

For Members—Townshend S. Brandegee, Civil Engineer, proposed by Hermann Kower, H. C. Behr and E. J. Molera; Byron Jackson, Manufacturer, proposed by John Richards, H. C. Behr

and E. J. Molera; Alpheus Bull, Jr., Mechanical Engineer, proposed by H. C. Behr, F. Orton and John Richards.

For Associates—Dr. H. H. Behr, Physician and Scientist, proposed by H. C. Behr, Hermann Kower and E. J. Molera; Dr. H. W. Harkness, President California Academy of Sciences, proposed by John Richards, E. J. Molera and Ross E. Browne; Dr. Franz Kuckein, Physician, proposed by Hermann Kower, F. Orton and E. J. Molera; Edward Schild, Accountant, proposed by Otto von Gelderen, H. C. Behr and E. J. Molera.

Publications received by the Society:

"Proceeding of the American Academy of Arts and Sciences," from May, 1888, to May, 1889; "Transactions of the American Institute of Mining Engineers, Washington," meeting February, 1890; Annales Ponts et Chaussees," June 1890.

President Richards suggested that a visit be arranged by the members to the U. S. Navy Yard at Mare Island. He also referred to the subject of elevators, and mentioned incidentally that the Hall Elevator had given some excellent results of efficiency, and that an inquiry would be of great interest to the Society.

Mr. Calvin Brown, Civil Engineer U. S. Navy, then addressed the members on the history, manufacture and application of calcareous hydraulic cements. This address, highly appreciated, led to an interesting discussion of some length. Mr. Molera asked how long a time it required for the complete aeration of the cement, Mr. Brown replying that it depended upon the article, the usual time being from one to three weeks, as the case might be. Mr. Percy inquired whether cement, during a sea-voyage, underwent any chemical change, whereupon Mr. Brown said that it frequently did.

In reference to the practicable thickness of layers, it was said that it was customary to spread the concrete from eight to ten inches, but that blocks had been made eighteen feet thick in Dublin Harbor.

Mr. Molera proposed a vote of thanks to Mr. Calvin Brown for the able and entertaining discourse, which was extended, the

President instructing the Secretary to prepare a written testimonial of the Society's appreciation for Mr. Brown's valuable paper.

The committee appointed to visit the breaking of one of the experimental cement and iron floors, constructed for that purpose under the patents of Mr. P. H. Jackson, made the following general report in an informal manner: That two members of the committee had visited the experimental station, and had been courteously received by Mr. Jackson. That general observations of the break had not been possible, for the reason that the ground had settled under the weight, so that the floor became warped and strains were introduced that the structure was not designed to resist. These conditions caused the floor to give away under a load of about 900 pounds per square foot. That it is to be regretted from an engineering standpoint that the floor was tried under conditions to which it would not be subjected in practice. But the test, however, helped to sustain the established fact that concrete and iron constructions are of the greatest efficiency, showing that even under adverse circumstances good results are obtainable.

In connection with this subject, the committee ventured to suggest that it would be of advantage if parties wishing the Technical Society to interest itself in experiments would let the Society know thereof in the beginning, or at least before preparations for the experiments have been completed, so that steps could be taken to secure the most accurate observations, from which detailed reliable data might be obtained for the future.

These statements regarding the subject of the tests were submitted by H. C. Behr, member of the committee.

Mr. P. H. Jackson then made a few remarks about his method of construction.

Adjourned.

H. C. Behr, Acting Secretary.

REGULAR MEETING.

October 3, 1890.

Called to order at 8:30 P. M. by President John Richards.

The minutes of the last regular meeting were read and approved.

The following gentlemen were elected to membership in the Society:

Members—Townshend S. Brandegee, Byron Jackson, Alpheus Bull.

Associates—Dr. H. H. Behr, Dr. H. W. Harkness, Dr. Franz Kuckein, Edward Schild.

The following propositions were read and disposed of in the usual way:

For Members—Ralph H. Moore, Mechanical Engineer, proposed by H. C. Behr, A. Schierholz and H. Vischer; Edgar H. Booth, Mechanical Engineer, proposed by John Richards, H. C. Behr and F. Orton; Carl A. Stetefeldt, Mining Engineer, proposed by H. C. Behr, John Richards and H. Vischer; S. B. Connor, Mechanical Engineer, proposed by A. Schierholz, James Spiers and John Richards; M. B. Dodge, Mechanical Engineer, proposed by John Richards, H. C. Behr and Otto von Geldern.

The President referred to the proposed visit of the Society to the U. S. Navy Yard at Mare Island, and stated that arrangements were making with the Navy Yard authorities, and that the members would be informed thereof in good time.

The death of Mr. Emil Adler, at one time a prominent member of the Technical Society was announced by the Chair. The deceased met his death suddenly at Portland, Oregon, a few days ago.

Upon motion a Committee was appointed to draft suitable resolutions of condolence and sympathy for the relations and friends of the departed member, consisting of Messrs. Gutzkow, Percy and Vischer.

Mr. H. C. Behr, Mechanical Engineer, then read a paper

entitled: "Experimental Works for Ores requiring Coarse Concentration," which was discussed at some length.

A vote of thanks for the author was passed.

Mr. F. Gutzkow communicated to the Society a plan for a new hydraulic safety device for elevators, invented by himself, the principle of which he explained by the aid of sketches on the blackboard. Remarks were made by several members regarding the device, the President stating that in his opinion an elevator should be so constructed as to require no additional mechanism to insure its safety.

Adjourned.

OTTO VON GELDERN,
Secretary.

REGULAR MEETING.

November 7, 1890.

Called to order at 8:30 P. M. by President John Richards.

The minutes of the last regular meeting were read and approved.

The following gentlemen were elected to membership in the Society:

Members—Ralph H. Moore, Edgar H. Booth, Carl A. Stetefeldt, S. B. Connor and M. B. Dodge.

The following names were proposed:

For Members—John Norbom, Mechanical Engineer, proposed by A. Schierholz, H. C. Behr and Otto von Geldern; Constant Meese, Mechanical Engineer, proposed by H. C. Behr, James Spiers and George F. Schild; Joseph J. Perkins, Mechanical Engineer, proposed by H. C. Behr, B. McIntire and Charles J. Koefoed; Frederick Gottfried, Mechanical Engineer, proposed by John Richards, H. C. Behr and Geo. F. Schild; J. B. Pitchford, Mechanical Engineer, proposed by H. C. Behr, John Richards and Geo. F. Schild; Henry Charles Tabrett, Mechanical and Marine Engineer, proposed by A. Schierholz, H. C. Behr and Otto von Geldern; William Leichter, Mechan-

ical Engineer, proposed by A. E. Chodzko, H. C. Behr and Otto von Geldern.

For Associate—A. P. Brayton, proposed by H. C. Behr, H. T. Power and George F. Schild.

Mr. F. Gutzkow referred to his hydraulic brake for house elevators, and gave a very interesting description of experiments made by him with cement-mixtures, variously applicable in technical works. It led to a general discussion.

Mr. Hubert Vischer then introduced a Thomas' Calculating Machine, kindly placed at his disposal for the benefit of the Society by Mr. Thomas Price, and elucidated the principles upon which it can be made to solve numerous simple as well as intricate problems, Mr. Owens manipulating the machine, while Mr. Visher explained the mechanism.

This proved of considerable interest to the Society, and after conclusion a vote of thanks was passed for Mr. Owens for bringing the machine.

The contemplated excursion to the Mare Island Navy Yard was referred to, the President stating that the authorities in command had kindly given permission to visit the yard, requesting that they be notified before hand of the day of the visit.

Upon motion of Mr. Keith to appoint a Committee to make the necessary arrangements for such purpose, Messrs. Schild and Browne were chosen.

Mr. Vischer spoke of the Folsom Dam as an interesting object and well worth a visit, stating that arrangements might be made to that end.

The Committee on drawing suitable resolutions commemorative of the death of Mr. Adler was granted further time.

Adjourned.

Otto von Geldern,
Secretary.

REGULAR MEETING.

December 5, 1890.

Called to order at 8:30 P. M. by President John Richards.

The minutes of the last regular meeting were read and approved.

The following gentlemen were elected to membership in the Society.

Members—John Norbom, Constant Meese, Jos. J. Perkins, Frederick Gottfried, J. B. Pitchford, Henry Charles Tabrett, William Leichter.

Associate—A P. Brayton.

The name of Alex. J. McCone as an Associate Member was proposed by H. C. Behr, C. A. Stetefeldt and Hubert Vischer.

A communication was read from the American Society of Mechanical Engineers in reference to an exchange of publications, and the donation of six volumes of past transactions was announced.

The Secretary was instructed to acknowledge this very acceptable addition to the Society's library in proper form.

The death of Geo. C. Knox of Los Angeles, a member, was communicated to the Society, the President requesting that a suitable letter be written to the widow.

Mr. Adolph Lietz read a paper entitled: "How to Tell a Good Surveying Instrument," which was discussed at some length.

Mr. Luther Wagoner explained to the Society a graphical method employed by him, to determine the eccentricity of an instrument and to develop a table of corrections to be applied to vernier readings.

Mr. A. T. Herrmann, of San José, addressed the Society on the subject of "County Land Surveying," calling attention to

the very unmethodical and unsatisfactory manner in which such surveys are generally made and recorded, and proposed the enactment of a law by the State Legislature, which shall regulate this important work. He suggested the appointment of sworn and licensed surveyors, who shall give bonds and perform their work in accordance with the requirements of such an Act. Mr. Herrmann contemplates to bring this matter before the Legislature of the State and asks the Technical Society for its aid and support.

Mr. Wagoner moved that a Committee be appointed to confer with Mr. Herrmann in the matter of preparing a bill for the State Legislature, to report at the next regular meeting. Carried.

The President appointed Messrs. Luther Wagoner and Otto von Geldern. Mr. C. E. Grunsky was subsequently added to this committee.

Mr. N. S. Keith invited the Society to visit the factory of the Electrical Engineering Company, No. 21 Spear street, where dynamos and electrical motors for the transmission and distribution of power are a specialty.

The election of a Nominating Committee for the ensuing year was in order, and after a ballot the President declared the following gentlemen elected: H. C. Behr, A. d'Erlach, A. Lietz, J. C. Gilfillan and B. McIntire.

Mr. Geo. F. Schild, of the Committee on Excursion to the Mare Island Navy Yard, reported the late machinery not all in place, and suggested waiting until the foundation of the new construction shop is finished.

Adjourned.

Otto von Geldern,
Secretary.

REGULAR MEETING.

January 2, 1891.

Called to order at 8:30 by President John Richards.

The minutes of the last regular meeting were read and approved.

Mr. Alex. J. McCone, of Virginia, Nevada, was elected an Associate Member, and the following names were proposed:

For Members—John L. Heald, Mechanical Engineer, proposed by John Richards, Herman Kower and H. C. Behr; Edward N. Robinson, Civil Engineer, proposed by Aug. J. Bowie, Jr., L. L. Robinson and G. F. Allardt; Edward Hooper, Mining Engineer, proposed by Luther Wagoner, John Richards and Hubert Vischer; Joseph C. Sala, Mathemathical Instrument Maker, proposed by Luther Wagoner, Hubert Vischer and G. W. Percy.

The donation of a large map of Santa Clara County by Herrmann Brothers was announced.

Mr. A. T. Herrmann, of San Jose, submitted a draft of a proposed act to regulate land surveying, which had been drawn up by the Committee appointed at the last regular meeting.

Professor Soulé moved that the bill be printed and sent to each member for suggestions, continuing the Committee meanwhile.

Mr. Herrmann stated than an immediate action was necessary; that if continued until the February meeting, it would be too late for legislation.

Mr. Vischer suggested leaving it for the annual meeting on the 23d of January.

Mr. Wagoner amended the motion to the effect that a special meeting be called one week from to-night, that the members be so informed and that a copy of the proposed act be sent to each for his recommendation or suggestions, to be returned to the Secretary by that time. Motion carried as amended.

The Nominating Committee, consisting of Messrs. Behr, d'Er-

lach, Gilfillan, McIntire and Lietz, submitted the following names recommended for the offices for the ensuing year:

For President—John Richards.
For Vice President—Luther Wagoner,
For Treasurer—Geo. F. Schild.
For Secretary—Otto von Geldern.
For Directors—Hermann Kower, Ross E. Browne, C. E. Grunsky, James W. Reid, Alpheus Bull.

Mr. R. B. Elder, of the Pacific Electrical Storage Company, then addressed the Society on the subject of "Electrical Accumulators and their Application," illustrating the discourse by sketches and a uumber of apparatuses.

A vote of thanks for Mr. Elder was passed.

An invitation was extended to the members and guests to attend an exhibit of the electrical lighting plant at Swain's Bakery after adjournment.

Meeting adjourned.

OTTO VON GELDERN,
Secretary.

SPECIAL MEETING.

January 9th, 1891.

Called to order by Mr. Luther Wagoner, Acting Chairman, at 8:30 P. M.

The meeting was called for the purpose of considering the proposed Act to regulate land surveying, framed by Mr. A. T. Herrmann.

The Secretary read copies of the printed Act as they had been returned by individual members with recommendations, suggestions and proposed changes. All were in favor of the bill, but the majority wanted it modified.

Mr. Allardt read some radical changes that he thought desirable and necessary.

Mr. C. E. Grunsky said that it was not entirely clear what was wanted. Said that the Society should come to an agreement this evening, and then let the committee construct an Act on the agreement.

Mr. Herrmann stated that he had been informed upon good legal authority, that a judge could not pass upon the qualifications of a surveyor and grant a license. In a county the Board of Supervisors would be the highest authority, and that either this body should have the power, or that a Board should be created for the purpose.

Considerable change was also suggested in reference to the section regarding trespassing, which Mr. Herrmann read.

Mr. Grunsky said the first thing to decide is: who is to give the license—the Board of Supervisors, or a special Board created for this duty?

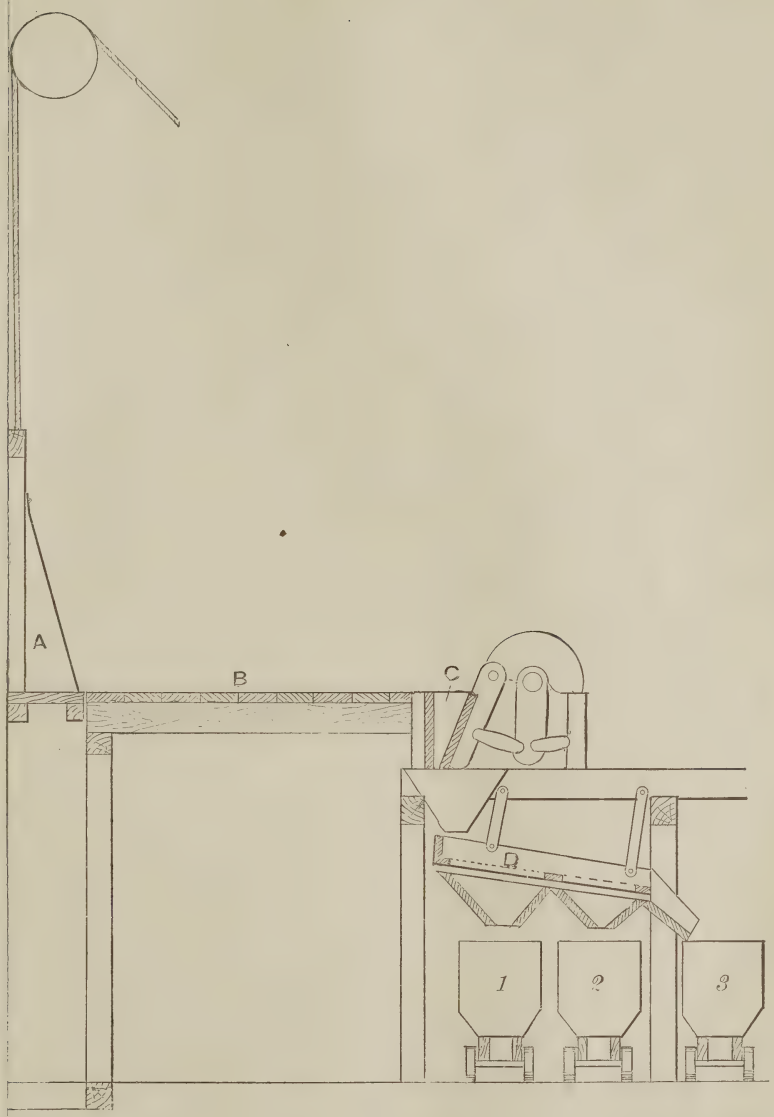
Three members of the Technical Society were suggested to constitute a Board of Examiners.

After considering many of the details of the bill, Mr. Allardt moved that it be referred back to the committee for reconstruction upon all suggestions considered this evening; that this committee have power to act and prepare a final bill for legislation. Carried. Mr. C. E. Grunsky was added to the committee.

Adjourned.

OTTO VON GELDERN,
Secretary.

NOTE.—A meeting of the committee took place on January 10th and 11th, at the office of Mr. C. E. Grunsky, where the Act was entirely rewritten.



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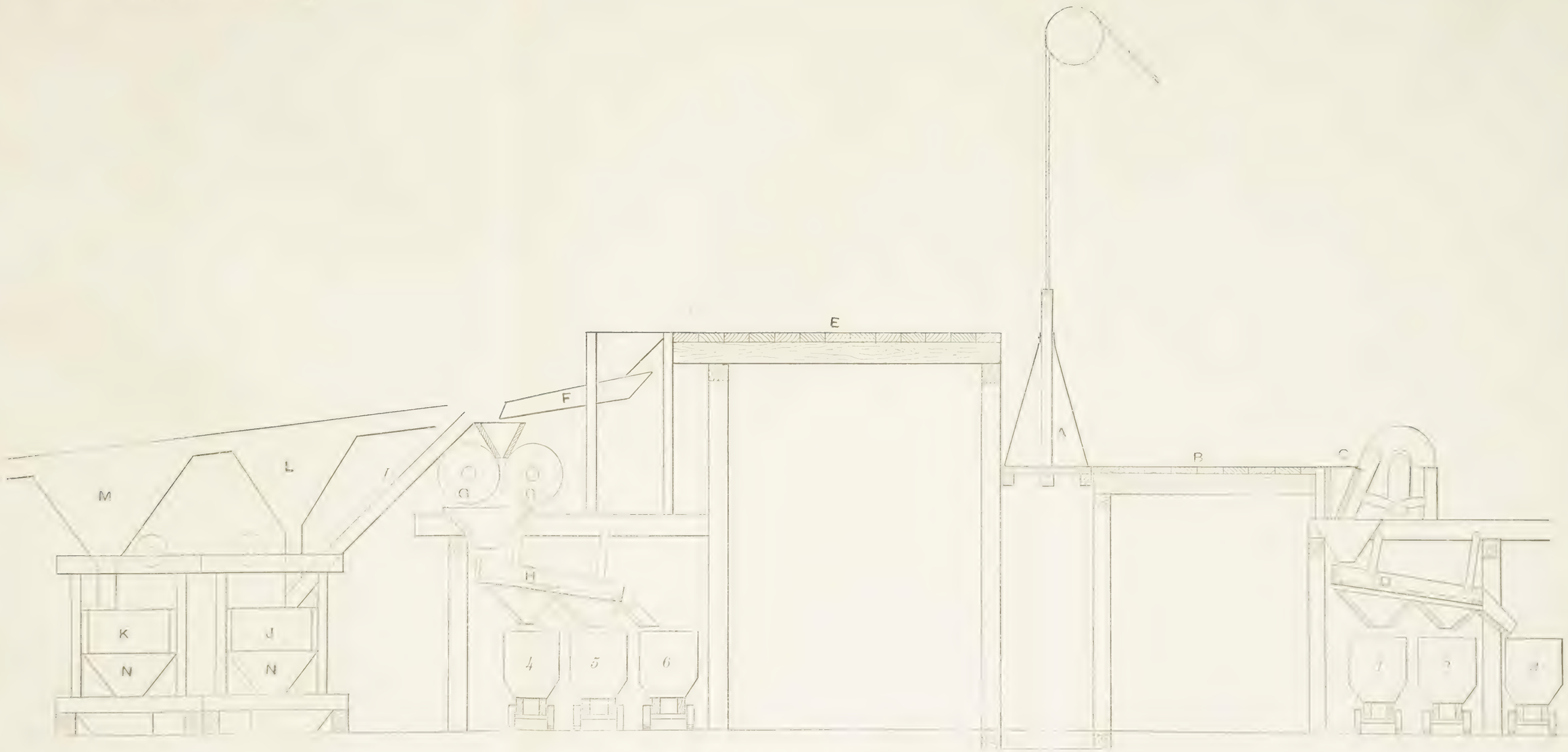

SKETCH OF EXPERIMENTAL CONCENTRATION PLANT.

TECHNICAL SOCIETY OF THE PACIFIC COAST.

SAN FRANCISCO, CALIFORNIA.

INSTITUTED APRIL, 1884.

TRANSACTIONS.

NOTE —This Society is not responsible, as a body, for the statements and opinions advanced in any of its publications.

(VOLUME VIII. No. 1.)

STREET PAVING IN SAN FRANCISCO.

The Defects, and Methods Suggested for their Remedy.

BY S. HARRISON SMITH, MEM. TECH. SOC. P. C.

[Read April 10, 1891.]

INTRODUCTION.

Perhaps there is at this time no subject (with the exception of sewerage) which calls for more interest and attention from our public generally than that of street paving. For many years back we have been struggling with this problem, under what seems to me to be very unfavorable conditions, and experiment after experiment has been tried with but doubtful success. In fact, in nearly every case such experiments have proved absolute and expensive failures. But the time appears to have arrived when the municipal authorities have concluded to alter these conditions, and careful investigations have been instituted by them in order to obtain the opinion of experts and men of science upon this complex question, so that hereafter such pavements as may be laid shall be of the most lasting material and of the best construction.

It is not intended by the author of this paper to embody therein any scientific or theoretical questions, but to draw out a discussion on purely practical grounds.

In order to consider this subject in the manner proposed by me, it is only necessary to give a short description of what has been done, of what is being done and of what it is proposed to do in this connection, and to make such suggestions as may seem proper.

EXPERIMENTS TRIED IN SAN FRANCISCO DURING THE PAST DECADE.

In 1870 there was a special committee of the Board of Supervisors appointed to examine street pavements, and recommend some class of the same for general adoption. The report of this committee has been read by me with much interest, and extracts therefrom may be quoted from time to time in this paper. The following named pavements are known to have been tried in San Francisco: Nicholson wood, Stow foundation, ordinary plank, Williams' composite, cobble, basalt block, composite limestone and asphaltum, and bituminous rock. There are many other classes of pavements whose merits have been advocated by their respective inventors or other parties in interest; but one of the objects of this paper being brevity, it has been deemed unnecessary to take notice of any classes of pavements other than those which have been actually experimented with in San Francisco.

NICHOLSON PAVEMENT.

The method of laying this pavement is as follows (the ground upon which it is to be laid having been brought to an even surface of the proper shape): The floor, which consists of pine planks of uniform thickness—generally two inches—is laid lengthwise of the street,

covering the entire ground. These planks are covered with tar by means of a broom; they are then turned and tarred on the other side. Then blocks of the same wood six inches long, three inches thick, and eight or ten inches in whidth, are set lengthwise across the street in rows, each block being well coated with tar before being placed. As each row of blocks is laid, a pine strip six or eight feet long, three inches wide and three-quarters of an inch thick is placed against and nailed to the blocks; then another row of blocks is laid, and so on. This leaves a groove between each row of blocks which is filled with a mixture of heated asphaltum or tar and clean gravel, which while hot is rammed with an iron of suitable thickness to fill the groove. The whole surface is then covered with coal tar, over which is spread a coating of coarse sand or fine gravel.

The special committee appointed by the Board of Supervisors when speaking of this pavement in its report, says: "The Nicolson has proved a failure, principally from the rapid dry rotting of the fir blocks used." "On Bush street, between Powell and Mason, the Nicolson was laid in 1867, and long since it became evident that it must prove an unsatisfactory and expensive pavement. It has been several times repaired, and now," (in 1870), "requires a liberal outlay of the people's money, with the prospect of abandonment ere long." They also found that this pavement swelled during the rainy season to such an extent, as to cause great damage to surrounding improvements. They allowed four years as the limit of its life.

STOW FOUNDATION PAVEMENT.

This pavement when laid is, in appearance, almost identical with the Nicolson, but in fact differs considerably therefrom. The main differences consist in this

pavement having no foundation beyond the preparation of the earth into a regular and smooth surface; the blocks being laid directly thereon with the fibers of the wood vertical, and that between each row of blocks, wedges made of boards, about six inches in length and nearly the width of the blocks, are driven some inches below them (the blocks). The remainder of the construction is similar to that of the Nicolson; the space between the blocks being filled with gravel and asphaltum or tar, and the whole surface covered in the same manner as the previously described pavement.

The committee, before referred to, preferred this pavement to the Nicolson, but only estimated its life at from five to six years. The following, taken from its report, may be of interest: "The Stow on Battery, between Vallejo and Green streets, was laid in January, 1869, and has been subjected to the excessively heavy transportation incident to Battery street and the North Point Docks and Warehouses. Your committee has closely watched for evidences of weakness in this pavement at this point, and has failed to discover any under the heaviest loaded trucks." But in spite of this account the pavement has passed into disuse, and we can only judge that a more extended experience showed similar or as great defects as were found in the Nicolson.

ORDINARY PLANK PAVEMENT.

It is hardly necessary to give a detailed description of this class of pavement, as it is familiar to all, having been but recently in general use in our city and in many localities still appearing. It consists of a framework of scantling, upon which redwood planks are nailed. There is little or no pretense at any previous preparation of the surface, or any exact method of construction. The troubles with this pavement are too well known,

and its abandonment of too recent date to need further remarks.

WILLIAMS COMPOSITE PAVEMENT.

This pavement is one with a foundation of concrete (Williams called it stone) and a wearing surface of wood, combined by a mixture of asphaltum, and covered by a coating of the same mixed with sand. It was claimed by the inventor that wood pavements perished more from the decay at base than from the wear on the surface, and that as the reverse was the case with stone pavements, he had succeded in solving this great problem. This pavement was only tried in one or two localities, notably New Montgomery street, in front of the Palace Hotel, and on McAllister street. The failure can only be supposed from the abandonment.

COMPOSITE LIMESTONE AND ASPHALT PAVEMENT.

This is a patent pavement just being brought before the notice of the public. It consists of blocks (or bricks) compressed by machinery, composed of an admixture of limestone and Trinidad asphalt; these blocks are laid in rows upon the ground prepared for them; they are then compressed, bringing them to an even and compact surface. A specimen of this pavement can be seen on O'Farrell, at its intersection with Grant Ave. and Market street, which seems to have stood its few years' use tolerably well. It is claimed by the inventors of this pavement, that it can be laid as cheaply as the ordinary bituminous rock.

The remaining pavements are those that are at present being used throughout the city, viz: Cobble, basalt block and bituminous rock. Description of the methods of laying these is unnecessary at the present stage of this paper, as the reference (which is proposed) to the

specifications in use by the city, will clearly bring out all points connected therewith.

PAVING SPECIFICATIONS, ETC.

Up to January, 1890, the cobble was about the only class of pavement having any permanent specifications or regulations governing its construction. These regulations simply provided that the stones should be selected, that they should not exceed nine inches, or be less that seven inches in length; that they should be set upright, smaller end down, close together in a bed of good, clean sand, not less than twelve inches deep; that they should be well rammed three times, well watered before the last ramming; then after being swept, the surface should be covered two inches deep with beach gravel or finely broken rock. For the other classes of pavement specifications were made as required.

In June, 1890, the then Board of Supervisors passed an order adopting specifications for all classes of street work, excepting sewers. In these specifications are included among other classes of work, macadamizing, cobble, basalt blocks and bituminous rock pavements.

The first mentioned (macadamizing) it is not thought advisable to notice, as it has never been considered by the author as a pavement. The specifications for cobble are identical with those previously mentioned, thus leaving only the basalt block and bituminous rock specifications to be noticed.

BASALT BLOCK PAVEMENT.

The specifications for this class of work adopted in January, 1890, provide that the roadway shall be excavated fourteen inches below the grade. A bed of concrete is then to be laid six inches in depth, and in the proportions of 1, 2 and 7 of Portland cement, sand and

broken stone. Upon this foundation, and bedded in sand, the basalt blocks are set; the regulation size being, depth from seven to eight inches, thickness from three and three-quarters to four and one-half inches, length not less than eight inches. A light coat of beach gravel or finely broken rock is then to be spread over the entire surface, and lightly rammed; the work is then to be inspected by the superintendent, after which more gravel or finely broken rock is spread over the surface and broomed in, after which it is to be thoroughly rammed, and gravel or finely broken rock spread an inch deep over the entire area.

BITUMINOUS ROCK PAVEMENT.

The specifications adopted in 1890 for this class of pavement provide that the roadway shall be excavated eight inches below grade. Then a concrete foundation of six inches in depth shall be laid, said concrete to be composed of 1, 2 and 7 parts respectively of Portland cement, clean sand and hard rock. On this foundation shall be laid a covering of bituminous rock two inches in depth. They also provide that this rock shall contain 14 per cent. of bituminous matter. The preparation of this material shall be by means of hot air, hot water or other process, but it shall not be reduced by any process liable to burn it.

In February, 1891, the present Board of Supervisors amended these in so much as to leave out the concrete foundation under the blocks. The dimensions of the blocks were slightly changed to the following width: not less than three and three-quarters or more than four and one-half inches, depth not less than seven or more than seven and one-half inches. The remainder of the specications were left the same as formerly.

This order embodying these specifications was not signed by the Mayor, but after several consultations held in his office between interested parties and experts, he returned the order, suggesting numerous changes to be made in the specifications for bituminous rock.

The principal suggestions were an increase of one inch in depth of original excavation;

The removal of all decomposed matter and debris;

The testing of the cement;

The restrictions placed upon the quality of stone to be used;

The moistening of the surface of the concrete foundation for seven days;

The increasing of the bituminous rock covering to three inches.

I have hastily reviewed about all the important steps that have been taken in the matter of street paving up to the present time, and it now only remains for me to make the suggestions that seem proper and to draw the conclusions to which the known facts seem to point.

CONCLUSION AND SUGGESTIONS.

As said before in this paper, we in San Francisco have had many expensive and futile experiments in street paving, and it would seem about time that some plan should be adopted for such work by the proper authorities that will insure an economic and durable roadway. There is no doubt but that what would be advisable for one section of our city, would be entirely unfit for others; therefore we have to consider more than one class of pavement. But before any pavement can succeed, it would appear to the author that a proper cross-section should be adopted for the streets which would be based upon the following rules: The crown of the center

of the roadway should in no case be much, if any, higher than the curb of the sidewalk and sloping on either side of this center line toward said sidewalk with a curving and ever increasing slope, and regular formed gutter-ways should be planned, sufficient in area to carry off all waters liable to fall on the surface. In considering a roadway, it must strike the most casual observer that there are two qualities (apparently opposed to each other) requisite for the formation of a good pavement; these are solidity or rigidity, for resistance to heavy loads and constant traffic, and elasticity, for the preservation of vehicles and stock.

Until these qualities are combined in their proper proportions no perfect pavement can be obtained. Allowing this as an axiom it may then be assumed that where the wearing surface is rigid, the foundation or bed should be more or less elastic and, conversely, that where the wearing surface is elastic the foundation or bed should be rigid in proportion.

In determining the sections of our city in which either a rigid or elastic wearing surface should govern, it is necessary to consider the amount, weight and rapidity of the traffic prevalent in such sections.

In those portions of our city having a great amount of heavy and slow traffic, such as trucking and general business hauling, the rigid wearing surface is necessary. In our residential districts, where there is little except pleasure driving, the smooth and elastic surface would seem to be the best. But here again comes in another feature, namely, the amount of grade allowable on such smooth surface. It appears to me that six or eight per cent. grades would be the greatest advisable in this climate for such surfaces as bituminous rock or asphaltum; although Eastern experts fix the maximum at consider-

ably less. As a great portion of our residence districts have grades greatly in excess of the above, it would seem that some special class of pavement should be adopted for such cases. This would, however, open up an almost endless field of discussion. I will therefore (in the present paper) simply confine myself to a consideration of the two classes mentioned above.

Of the classes of pavements having rigid wearing surfaces the most prominent are granite and basalt blocks. The former of these is greatly preferred by the author, as in wearing it is not likely to assume a smooth and slippery surface. But the proper rock of this kind is so scarce in this neighborhood that the expense of laying such a pavement would be very great. We can, however, consider these two wearing surfaces as identical with regard to their construction, so, for convenience they will both be considered as basalt, this being the one used with us on account of the expense incurred.

Taking, therefore, basalt blocks as our wearing surface, the author wishes to submit to the Society his suggestions as to the size of blocks and the proper methods of laying the same.

The size of blocks should be as near as practicable: length, seven inches; width, four inches, and depth six inches. They should have rectangular faces, and should be well dressed on all sides; a variation or projection of half an inch is the greatest that should be allowed.

In considering a foundation for this pavement, we have three classes of ground upon which to build, viz: that which has been filled in and is, therefore, liable to settlement; sand, which is shifting and unstable; earth or clay and rock.

Upon the filled-in ground I would suggest two methods: first, to excavate the ground to a depth of eighteen

inches, such surface to be brought by rolling or tamping to a curved plane parallel with the proposed finished face; over and in contact with this to be laid a bed of concrete eight inches in thickness, whose tamped and completed surface shall also be parallel to the finished surface of the proposed pavement. Upon this bed of concrete, after it is well set, shall be spread four inches of fine sand, on which the blocks shall be laid at right angles to the street, in courses, each course to break longitudinal joints with the one preceding; fine gravel or coarse sand will then be swept over the surface into the joints, the blocks to be driven to the proper finished contour; after this has been thoroughly done, coal tar shall be poured into all the joints, then a thin layer of gravel should be spread over the entire surface.

The second method spoken of is the substitution of planking for the bed of concrete; in other respects the process and material would be practically the same. In places where the foundation is sand, I would excavate to the depth of twenty inches, roll the bed thoroughly, fill in (in place of concrete) with good clayey earth to a depth of twelve inches, more or less, as required to make a surface, which, after being thoroughly watered, rolled and rammed, shall be ten inches below the proposed surface of the roadway; the remainder of the work to be finished as described above.

Where we encounter rock upon, or too near the surface, the roadway should be excavated to a depth of some twelve inches, all inequalities carefully filled in with concrete; then the surface shall be filled in with a bed of good sized gravel, said bed to be three inches deep when rolled; over this spread a bed of sand, also three inches deep when rolled, the setting of the blocks and the remaining processes to be as before.

Of the classes of pavements having what we have termed elastic wearing surfaces, those most in use in the Eastern States are a composition of asphalt with sand and lime (the Trinidad and Cuban asphalts being the ones generally preferred). In Paris they use an asphalt which in its natural state contains a large percentage of lime. In California we use what is known as bituminous rock; this is a natural product, and is mostly composed of sand and volatile oils. It has, however, a small percentage of bituminous matter in its composition. This last mentioned material, owing to its plastic qualities, makes by no means so durable or satisfactory a pavement as the preceding ones. But however these substances may differ in their component parts, the necessary foundations and the methods of laying them are the same, with the exception that where laid in sheets, Trinidad or Cuban asphalt should be from two to three inches in depth; where, as in the case of bituminous rock, nowhere should its depth exceed two inches. The reason for this is due to the plastic qualities of this material; for where exposed to the softening influence of the sun, the greater the depth of any plastic body, the more sensitive it is to unequal compression upon its surface. Asphalt pavements are laid in two forms, sheeting and blocks. These we will consider separately.

Asphalt sheeting should be laid between two or three inches in thickness for Trinidad or Cuban asphalt, and from one and one-half to two inches for bituminous rock, with a base of cement concrete six inches in depth. Previous to the laying of the concrete-bed, the roadway should be properly prepared as described in the suggestions for other kinds of pavement.

The concrete should then be put in and compressed to a surface exactly parallel to the proposed finished sur-

face of the street, and should be properly covered and protected until set.

Upon this should be spread a thin layer of pure asphalt, and then the wearing surface proper, which should be thoroughly compressed, after which a small quantity of cement should be swept over it, and the surface well rolled.

The gutter-ways should be formed of selected stone blocks laid as headers, which shall form a broken line toothing into the asphalt; the joints of such blocks to be filled with cement or coal tar. Where the street is traversed by a car track, a strip of stone blocks should be laid next to said track, after the same manner as those forming the gutter-way.

In the classes of asphalt blocks generally used I have little confidence, as they are mostly covered by patents; and so much depends upon the care with which they are manufactured. It has been held in some of the Eastern cities where these blocks have been used, that their failure is attributable to experiments in different qualities of asphalt, even when the chemical analysis of these asphalts were almost identical with the best known material. It would seem to the author, however, that there must have been some fault in the method of manufacture.

I understand that it is proposed in this city to lay block asphalt without a foundation. This I think exceedingly ill advised, for if it has any qualities not belonging to other pavements which would render a foundation unnecessary, I fail to see them.

In conclusion, I will state that I have now hurriedly reviewed this subject of street paving, not to its fullest capacity by any means, but to such an extent, I hope, as will bring out such a discussion as the Society may think proper.

I have attempted to show the futility of experimenting with patent pavements. Also to narrow down the advisable classes of pavement for use in this city to two, viz: the granite block for the portions of the city subject to heavy traffic, and the asphalt for those subject to the lighter classes of vehicle. It, therefore, remains only to ask of the Society such comment as its individual members may see fit to make.

DISCUSSION.

Mr. Gutzkow—Mr. President. Regarding bituminous rock, there seems to be an impression that one pavement is as good as another, and the question is never asked from what locality in California it comes. Elsewhere it is very different. In Paris bituminous rock from a certain mine or a certain district is stamped so that it may be known in what exact locality it is gotten, and none other is accepted as a rule. Here, if it only looks black, it is thought to be all the same material.

There is a great deal of difference in bituminous rock. The bituminous rock of California is entirely unfit for pavement. It is much too soft. We have made ever so many experiments, and in no way have they been satisfactory. After a little while the pavements show the horses' hoofs and wagon impressions. I think a few tests on a simple scale would be advisable, and would save a great deal of expense which is incurred when tried on a large scale. In the reports of the State Mining Bureau some statements have been made regarding this rock, but they do not give us any idea of how much carbonaceous matter or fixed carbon it contains, or anything of that character. The mixture is sand, some-

times eighty and ninety, and sometimes seventy per cent.

The great point is to find out at what temperature this asphaltum becomes soft. Some alphaltum can stand a great deal more heat before it softens than others, and some is very easily softened. For instance, if you press some asphaltum and have a certain weight on it, and expose it to a certain temperature, it will be found to be very soft. Material of such a nature is entirely unfit for street use. The asphaltum in France is not of such a character. It is limestone impregnated with asphaltum, while what we have is pure asphaltum or a mixture of sand, sometimes coarse and sometimes fine.

My observations for twenty-five years or more in California tend to show that the sidewalks are not much better now than they were then. The only sidewalks that stand are those which have an abundance of carbon and stone—something that will give sufficient hardness.

A question. Mr. President, I would like to ask what experiments have been made in regard to the saturation of bricks with asphaltum—has it been done?

Answer. It has been referred to in the paper just read and it was favorably commented upon.

Q. Have they ever been used here or elsewhere?

A. Here, in different parts of the city, I have seen it. For instance, at the corner of Taylor and Geary streets they have it, I think. It stood very well for a little while; then the asphaltum came off from the top, and nothing but bricks remained.

Q. You do not know how the bricks were prepared?

Mr. Gutzkow—They put them in something called asphaltum, but it is nothing but tar. They dip them

in, and the bricks may take a little. If the bricks are porous, they may take up a good deal of asphaltum, but if they are hard, and consequently good for pavement, they will not take up much, and you might as well not have any.

Mr. Herrmann—I do not agree with the opinion of the last speaker.

I have observed the bitumen or petroleum, as it is generally called, in Santa Cruz and San Jose, and I think it is the best street surfacing that is found in the world. The fact referred to by Mr. Gutzkow, that the horses' hoofs will indent it, is a sign of its goodness, for every impression so made will soon disappear again, and shows that petroleum wears like rubber.

The petroleum generally used in San Francisco, San Jose and Santa Cruz is sandstone thoroughly impregnated with crude oil. It is found in large deposits in Santa Cruz county and in the vicinity of formations carrying oil and gas. From what I can learn, it contains more or less paraffine and the greater or less amount of the latter seems to determine the wearing qualities of the petroleum.

In Santa Cruz its use was commenced some ten years ago. I have there seen a layer of petroleum not more than an inch thick on a foundation of broken lime rock, well rammed down, used for three or four years between the track of the horse railway, and neither wear out nor necessitate many repairs. The lime rock, so used for years as a foundation for petroleum covering, when taken up shows plainly how far the oil of the petroleum has penetrated. Generally this penetration is from three-eighths to one-half of an inch into the rock, thereby combining the two materials so closely that you can hardly separate

them. This penetration does not seem to take place with trap rock as a foundation.

In San Jose trap rock was chosen for a foundation by the authorities. Lime rock could not well be had for anything like reasonable cost, and the shale used in Santa Clara county for road covering, and generally known as Alum Cañon rock, was condemned by the authorities without trial.

That was the first serious mistake made, for the trap rock will never compress or cement together until the traffic has worn enough material off the edges of the rock to form a cementing material—whilst the Alum Cañon rock readily cements under pressure, and compacts more thoroughly under a roller than trap rock under the same pressure and six months additional use by traffic thereafter.

The trap rock foundation was made in the same manner as macadam. The trench, dug out to a proper depth, was hand-packed with large pieces of trap rock of irregular shape and from six to ten inches in diameter. Layers of smaller and still smaller rock followed, all carefully packed by hand, sufficient to give, after a thorough wet rolling with a 15-ton roller, a bed ten inches thick. Then the petroleum was spread one inch thick in the usual manner, evened with the rake and smoothed with the hot roller.

But the streets so made were failures. The trap foundation, apparently made with all possible care, did not have solidity enough and soon gave out in numerous places. It seems that the interstices were not completely filled by rolling, and the heavy traffic soon developed indentations or sinks in great numbers, and wherever these appeared the petroleum would crumble and wear away. Besides, the crown of these streets was

not made high enough to allow of proper drainage of rain water, consequently the latter would stand in pools in every indentation, softening and permeating the petroleum to such an extent that it would be crushed under heavy traffic.

The lesson was a dear one, but has been duly appreciated and we are now building streets in San Jose with a concrete foundation six inches thick. The covering of the petroleum is increased from one inch to two inches, and none is laid in the gutters, where the horse urine seems to destroy its vitality. The gutters are now made of basalt or trap blocks, set on a sand bed and grouted with strong cement. The two-inch covering of petroleum appears to be very strong and durable and lying on a rigid foundation that under no circumstances can give way, it seems to be just the thing for the lightest as well as for the heaviest traffic.

I can hardly conceive of any better and more generally useful pavement, and without hesitation pronounce it the coming street construction for our State.

Prof. Soulé—I would like to state from memory something about bituminous pavement laid in Oakland by T. L. Barker, in front of the Wilcox Block. In August, 1886, he got permission from the city authorities to put down this bituminous rock, using the old macadam as a foundation. That was about six inches thick. He smoothed it off, and put the bituminous material on top of it. If I remember rightly, it was the Santa Cruz rock. This was the first time it was introduced in Oakland. The thickness of the covering was two inches before, and one and one-half after rolling. This was laid on one side of the street, from the car-track to the curbstone. The other side of the street did not enter into this improvement at that time. That bituminous

rock pavement has been there I think five years. It has never been repaired, and is as good as new. It is on Broadway, between Eighth and Ninth streets, and is subject to the heaviest traffic and travel. Even in the gutters where the horses stand a good deal, there is very little injury to the bituminous pavement. I think that is a remarkable case. It may have been that being the first rock put down, they used greater care with it, so that the quality was of the very best. I don't know about that, but it certainly has worn exceedingly well.

There was no more bituminous rock put down in Oakland until two or three years ago. Then a very fine piece of work was done on Ninth street, between Broadway and Washington. This is a section that is traveled a great deal, but not so much with trucks and heavy teams as some other portions. I believe that work was done by the Santa Cruz or the Perine Company. They used extraordinary care. I think it has an eight-inch foundation of macadam, with a two and half inch covering of bitumen rock. The gutters are made of basalt blocks. That pavement has been down between one and two years; on very warm days it is as Mr. Gutzkow says, in crossing it, one leaves the impression of his foot. The impressions from the corks of the horses' shoes can be seen, as also ruts made by wagons, even those of light carriages; but the next day, if it is cooler, they will all have disappeared, and the pavement will be as smooth as when first made. So, as Mr. Herrmann says, in that case at least, it seems to possess the characteristics of ordinary india rubber. On the other hand, on Franklin street, where the bituminous rock was laid on macadam, it would seem that there these materials were not laid with so much care, and not quite as thick. The surface is not even, and in many places where there is a little de-

pression, the heavy trucks have broken it open, and it has a tendency to heap up in little hummocks in some places and to be depressed in others. That leads me to the conclusion that possibly the work was not very well done to begin with, and that sufficient attention was not paid to the foundation. I think it was not evened up enough, nor made solid enough. We have here one instance, the Franklin street work, not wearing very well, and on the other hand the Wilcox Block, which has proved exceedingly good. In a letter written by Mr. Barker on this subject, he says: "I believe in it as the very best, IF the work is well done, otherwise it will of course be a failure."

Mr. Raymond—It makes a vast difference how this pavement is laid, and also, as Mr. Gutzkow has said, where the material comes from. The materials from the different localities vary greatly in their composition, and require very different treatment before they are suitable for use as pavements. No one of the California material is, in my judgment, suitable for pavements if laid in its natural state, and each producing company should determine for itself the proper treatment for its material. I made a survey of the Ventura Company's mine last summer, and was very favorably impressed with the quality of that rock. It seems very different from the Santa Cruz material.

Q.—Is it asphaltum or petroleum?

A.—I don't know that there is any difference between California asphaltum and petroleum. The California petroleum seems to have an asphaltum base. How is that, Mr. Gutzkow?

Mr. Gutzkow—I cannot say as to that.

Mr. Raymond—I am told by those working it, that

the California petroleum seems to have an asphaltum base rather than a paraffine base. The Ventura rock is an unusually hard material as originally mined, and does not melt at anything like the temperature at which the other materials do. The Ventura Company—Messrs. Coit, Barton & Cowles—do not use their rock in its natural condition, but add to it, in melting, other materials. The exact treatment I am not familiar with. I think the company has put some pavement down at Palo Alto which has been satisfactory. And then it depends upon how it is put down. We have some sidewalks in Berkeley that are horribly thin and soft stuff. In the winter time it gets hard and cracks, and it closes up again as soon as the weather becomes warm, and in some places *weeds come up through it*. There is one other point I have not heard mentioned in regard to Mr. Smith's paper, and that is his preparation for basalt pavement in cases where it is built on sand. If I have noticed correctly, he only provides for putting clay on top of the sand, and a little more sand, and then the blocks. That seems to me a wholly inadequate foundation. It seems to me that the block pavement would certainly sink and swell in such cases. That has been the experience of cities in the East with which I have been acquainted, where the soil is more of a clayey nature, perhaps. There, so far as I know, they don't think of putting a pavement of granite blocks down without a concrete foundation. The foundation is always concrete, and then the spaces between the blocks are filled in with gravel and tar or asphaltum. It seems to me that even more on a sandy soil would be necessary to make a good concrete foundation than on clay, for the sand cannot be said to be "*confined*."

It seems to me that it will be a good thing for the Supervisors of San Francisco to lay side by side, where

the circumstances will all be exactly the same, strips as wide as may be necessary of all the various kinds of pavements—the various kinds of asphaltum pavements and block pavements.

In St. Louis I have seen what seemed to me quite a reasonable scheme. The heavy traffic is down on the streets near the river front, and more or less extends back into the interior of the town. The lower and heavier traveled portions are paved with granite blocks, and running out into the interior parts of the town, the streets are alternately asphaltum on concrete, and granite blocks on concrete, and the heavy traffic is forced on to the granite streets and the lighter upon the asphaltum streets.

A question. I would like to ask what the common rock is where this Ventura mine is?

A Visitor—Mr. President, I am interested in this thing, and can give some information upon the Ventura mine. The Ventura Asphaltum Rock Company's mines in Ventura are from four and a-half to ten miles from the seaboard. The outside formation is composed mainly of clay and chalk. It seems to have been compressed by some force of nature and brought up to the surface, and contains twenty-five per cent. of fixed bitumen. There is nothing volatile about it. There is some silica in it, and some lime, and a little ash. It commences to soften at two hundred degrees Fahrenheit, and melts at from four hundred and eighty to five hundred degrees. There is an absence of clay and dirt and we mix in sand with this asphaltum, and obtain a mixture artificially, which we claim is better than anything nature has produced throughout the State. We claim that this pavement will remain the same as laid, for fifty years.

Mr. Gutzkow—I think it would be well for the Board of Supervisors to forbid the use of four horse teams in this city. In Germany it is entirely forbidden. Nobody is benefited by the use of four horse teams except the proprietor.

Mr. Wm. Ham. Hall—I have been an observer of the wear and tear on pavements in San Francisco for a number of years, and have come to the conclusion that their failure is not so much due to what we see on top as to the foundation.

Referring to asphaltum and to bituminous rock pavements, it is fortunate that our cities are not to be governed by Mr. Gutzkow's opinion and mine, because if both our opinions were taken, we would not have any pavements at all. I understood him to say that our bituminous rock is not fit for pavements; I do not think there is anything else fit for pavements, at least under light travel.

I think that rock pavements, where light vehicles travel, are a barbarism, and it would be a great misfortune to this country if there were nothing else fit for use. Since our bituminous rocks, so called, are the best we have, our attention should be directed to how we can make the best use of them. If the parties who own these deposits are not capable of finding out how best to use their output, then I think it eminently proper for the city to take hold of the subject, and discover how the material from the different deposits can be used to the best advantage, else we must bring bituminous rock from France (or wherever Paris gets her supply), or move San Francisco there.

I think that an omission in Mr. Smith's paper is well supplied by what Professor Soulé and Mr. Herrmann have spoken of. That is, the provision of a wide gutter

of stone. Then, with asphalt well laid on good foundations, I think we will come as near to perfection as we can hope to get in this State, and to that end I think experiments can well be taken up, as Mr. Gutzkow has suggested.

Prof. Soulé—I think there is a limitation to the use of bituminous rock in cities that have steep hills, because I am satisfied that in cold or rainy weather it would offer such a smooth surface that it would be utterly impossible for carriages and horses to be driven over it. In Paris where they have asphaltum pavements—although somewhat different in character from this bituminous rock pavement—still they present the same exterior smooth surface. Particularly in cold weather I have seen more horses fall and slip in that city than I ever saw elsewhere. It is a very common thing to see horses slip there, and that on level streets. It will be so here with our bituminous rock, and it will be impracticable to use that covering on our steep hills.

Another thing, in very warm weather there will be a tendency for this skin to slip down hill and gather at the foot, becoming thin on the upper part, and accumulating on the lower portion.

Mr. Herrmann—I wish to call the attention of the members to the great difference in the practical handling of petroleum and handling asphaltum. I have used them side by side in Santa Cruz. The asphaltum is hard and glossy, almost like pitch, and to use it you boil it with coal tar; whereas, petroleum mixed with coal tar, would be entirely unmanageable. Only steam or boiling with water in open kettles will reduce it to a proper consistency for use. It is then put on the foundation, raked even with common rakes and then smoothed with heated rollers.

Now, as to the experiments that Professor Soulé spoke of in Oakland about laying petroleum on an old road, I have tried the same experiment successfully.

There was in San Jose great opposition to the petroleum, and in order to overcome it myself and two of my friends chose a street crossing with the heaviest traffic, scraped the top off clean and smooth and put about two inches of petroleum on it, and it lay there for years until the street was remodeled. There never was a hole in it or any wear to it. It shows to me conclusively that where petroleum is laid on a solid and smooth surface that cannot give away, that it will almost last forever.

There is one thing in regard to laying sidewalks with it. I have found that if you forget to put salt on the sub-grade before you cover it with petroleum, the latter will be broken and cracked by plants and weeds growing up through it.

The Chairman—There seems to be a concensus of opinion that asphaltum is the best thing. Nearly every speaker has touched upon the importance of a good foundation, and also on the fact that the foundation is generally wanting. I think it would be a good point if some discussion were had on that matter, in order to ascertain the cause of the bad foundations.

Mr. Grunsky—The bituminous surface is one of many advantages; I think everyone will admit that. The bituminous material that nature offers us here is very desirable. It is so good that even in the East and elsewhere it has been artificially imitated; they mix substances chemically as near like ours as they possibly can and such material is preferred there. It is united as thoroughly as possible with its foundation. Sometimes

it is laid upon a concrete foundation, sometimes upon macadam, but preferably now upon a base that is cemented with coal tar paving cement, as it is called. Broken lime is well rammed into place and covered with a layer of paving cement. A very small quantity is sufficient for the base itself. Then a binding course, perhaps one and a half to three inches in thickness, is laid upon this base, and this is covered with the bituminous material, which is very similar to that of Santa Cruz or Ventura, after the sand has been added. It makes a most excellent pavement. It is free from the waviness that is found in the bituminous rock laid upon concrete, which has a tendency to assume a wavy surface. Of course that varies with the thickness of the material and with its character.

I think that the tendency here should be to secure the best possible foundation—that is, the foundation that will best unite in the bituminous surface. If the bituminous material is placed upon concrete on an incline, there is a tendency to move.

The material that is used in making the bituminous surface in the East is Trinidad asphaltum, to which silicates are added. Trinidad asphaltum is used and pulverized lime, which has given very good results.

Mr. Vischer—This discussion has undoubtedly brought out some interesting facts, but coming up at the present time, while the Board of Supervisors are still engaged in preparing specifications, the question suggests itself, whether the discussion invited by Mr. Smith's paper was intended to have a bearing upon their work or not? I regret that the author is not present, or I should like to have asked this question of him.

It strikes me, however, that a more profitable field for inquiry than the one so far pursued would be to elicit

an expression of opinion from the Society regarding the methods which govern municipal paving work, rather than to seek to determine the merits or defects of any special material or method of laying pavement.

Under the present system, engineers have very little to say, so far as any of the important elements of the question are concerned, and this "specification system" clearly aims to take the subject of paving entirely out of the field where it legitimately belongs—with the engineers, namely.

Mr. Smith's paper enumerates the various devices which have been tried in the unsuccessful effort to obtain "something for nothing," which, at least until recently, appears to have been the main consideration.

The pavements first enumerated clearly aimed to dispense with foundations and provided for a surface only. The results were, of course, unsatisfactory. Latterly the public have gained insight enough into the matter to recognize the need of foundation as well as surface; and I believe the present tendency is to go to the opposite extreme and to construct pavements which are needlessly costly. I do not wish to say that any pavement is too costly if laid and maintained under the proper conditions, but unless these conditions are recognized and exist, true economy can be very easily overstepped.

I think I am not mistaking the facts in saying that the city has tried every device for paving the streets except the device of employing professional men to determine the requirements and leaving the execution also to the supervision of men whose business it is to look after such matters. The day will come, I hope, when the public will recognize that their true interests demand that the office of Superintendent of Streets be filled by an engineer—or if the political distribution of the loaves

and fishes precludes this, then, at least, that some deputy should be professionally qualified and should be vested with authority to exercise proper discretionary functions and carry improved methods into effect.

The root of the whole difficulty, the reason that San Francisco has always been poorly paved, lies really in this source.

The importance of the question in dollars and cents to the taxpayers cannot be easily stated too high, nor is there any matter which is more likely to permanently effect the growth of public prosperity.

The so-called "specifications" to which I have alluded, set forth the conditions, or rather the various sets of conditions, any one of which if complied with, entitle property owners to shift the burden of repairs and maintenance of the paving opposite their street frontages for ever afterwards from their own shoulders to those of the taxpayers at large.

The private interest and the community interest are not in harmony, and it is easy to foresee what a burden is in store for the city, and that, too, without prospect of reasonably well paved streets in the end.

With the passage of the pavement "specification" in the form of an ordinance, the responsibilities of the authorities practically ends. Any engineer will admit that what is good pavement under one set of conditions, will prove poor pavement under other circumstances, and any engineer of experience knows that no pavement, however excellent when laid, but will deteriorate unless properly cared for and systematically looked after when the first indications of weakness appear. There is nothing to which the "stitch in time" applies more forcibly than to roads and pavements, or in fact to any device exposed to heavy traffic.

Now the functions of the governing body as at present exercised, practically terminate where the real question begins. After having tinkered together the "specifications," no attempt is ever made to define the external conditions under which any one set may be used. It rests with the property owners of any one block to decide whether the pavement to be laid on their block shall be asphaltum, block, or, until latterly, a cobble pavement. The result of this system, or rather lack of system, is what we have before us; pavements of all descriptions closely following upon one another, without regard to traffic, grades or character of the locality; also asphaltum pavements laid on grades so steep that after a shower horses are afraid to pull a load up hill for fear of slipping, and with surfaces so smooth that brakes will not hold in going down hill. In other places we see macadam used where the grades are so steep that the surface water, failing to reach the gutterways, have completely cut through the rock covering of the street.

With all deference to the engineers whose public spirit may have led them to assist the Board in its deliberations, I think it will be generally admitted that the deliberations of the Board never exceeded very narrow limits. To do anything beyond providing a covering for the street, seems never to have been aimed at; the effect on stock and vehicles, or the safety and convenience to the public hardly appears to have received passing notice.

Street pavements is not a simple but a very intricate subject, and under the growing demands of traffic, a contest has been going on in the large cities of the world which is entirely analogous to that which has been maintained between heavy projectiles and heavy armor in naval construction.

A few thousand dollars spent in securing the best efforts of expert engineers would have been money saved to the city, and until their services are properly remunerated, it is not to be expected that engineers, however much actuated by public spirit, will be willing to devote time and study to settle questions which the public does not offer to pay for.

Among the suggestions to the Board the recommendation was made relative to concrete pavement foundations, that none but the best (consequently the most expensive) brands of cement should be used, and the quantity of cement recommended was very liberal. However, good as abstract advice, I question its soundness as long as concrete foundations are laid according to the customary practice. After the ingredients for the concrete are dry, mixed on a plank platform, laid on the bed prepared to receive the foundation, it is customary to apply the water through a common hose, attached to an adjacent faucet, which is allowed to run under considerable head while subsequent mixing with shovels goes on. It would be hard to state how much of the cement remains in the concrete when finally laid and how much is leached off into the sand or soil under the pavement. While such methods are permitted, why waste good cement by putting it into pavement foundations at all?

Another matter of importance is that at present there is only a nominal guarantee that pavements when torn up for repairs of pipes, etc., will be put back in good condition. In fact as long as our streets remain in their present transition style, I doubt whether too great outlay is real economy. One of these days, probably, the practice will come into vogue of laying the gas and water pipes, the sewers and all other paraphernalia now

strewed about at random in well constructed "subways" in which repairs and inspection can go on at any time without tearing up the street surface. When this point is reached, it will pay to adopt the highest forms of construction for our paving.

By that time the rate of interest on money will probably be lower than now, which will also justify greater outlay.

Mr. Manson—I was very glad to hear Mr. Hall speak of California material as he did. I do not know personally about the situation of European cities, but there are no cities or towns in the United States near which better material for paving exists. Our basalt or trap rock is of a strong, tough, and durable character, and is much superior to the granite used in many of the eastern cities. I believe in relation to asphaltum and bituminous matter that California can present a wider range and a better class of material than we have imported into this country from anywhere else, and that we have less excuse for bad pavements than any other city in America.

The main trouble with all our pavements is that there is a premium on bad work and too much "politics" used in making and repairing them. The city accepts a street when it has been put in a certain condition. It is to the interest of the property holder to spend as little as possible in getting the city to accept his street. The work is judged of, as a usual thing, by an utterly incompetent inspector, and is passed upon by a more incompetent Superintendent of Streets. As Mr. Vischer says, it needs an engineer. It needs an engineer not only of a wide range of experience, but one, just now, with a cast iron backbone.

We can continue to improve our asphaltum by refin-

ing it, and giving it that degree of toughness which is best suited to the particular use it is to be subjected to. There is no question that the various asphaltums from different places require different treatment.

Our streets have cost, so far as I have been able to learn from carefully going over the various reports of Superintendents of Streets, the sum of thirty-one million dollars that I know of. How much more in the matter of repairs, done by private citizens, it is impossible to state. The record is not available. Now London measures her age by centuries, where we measure ours by decades. London is still experimenting and improving, still tearing up streets and re-building them, and I don't think that we should stand still here and let our streets suffer until permanent underground conduits are made; if we do, I think not many of us will have the pleasure of driving over good streets.

Mr. Vischer—Concerning our basalts, I hardly share Mr. Manson's high opinion of the material. Much of it becomes very smooth after it has been for some time in use in pavements, and unless it receives more care than it usually receives, our basalt pavements soon fall into bad condition.

Mr. Manson—Some of our basalts are very hard, and they wear as slick as glass. The hardest were those used on Market street, between the cable roads and between the tracks; they were grouted in every joint, with the hardest cement. I kept an account of horses that I saw fall upon this pavement and all other pavements in the city, and the proportion was about nine to one on the Market street pavement, when first put down. I frequently observed as high as two and three a week. That number has decreased of late, for the reason that the roadbed has given out.

There is stone that is quarried both in Marin and Sonoma Counties which does not wear slick; its edge remains good, and it wears uniformly; it is a tough stone and does not give out, and it is the only material that will stand the heaviest teaming.

Q. What do you mean by saying that the roadbed was wearing out as regards to horses falling down?

A. It is giving out entirely, and they have been taking it out all along the line. Then again the roadbed is wearing down, which makes it irregular and uneven, so horses obtain a better foothold than at first.

A Member—In Paris, and very largely in the East, limestone and bituminous matter is used. The Germans, in paving Berlin, in their specifications have substituted for limestone coarse, sharp sand, and get a much better wearing surface, so far as its being slippery is concerned.

A Member—In Washington the plastic pavement is used, and there are extensive reports upon the subject. That city is very largely paved with that class of material.

Mr. Herrmann—I remember that the asphaltum pavement in Washington is very slippery, and in rainy weather it is unsafe for man or beast to walk upon it. This is particularly the case on Pennsylvania avenue, the crown of which is too low to allow of quick drainage of rain-water or melting snow.

Q.—Is it not a fact, Mr. Herrmann, that Washington has the reputation of being the best paved city in the United States?

A.—It is nicely paved.

Mr. Hall—A suggestion has been made that large and

heavy teams should be prohibited from traveling, at least, on some streets. To go with that, I would suggest that there be an ordinance providing that teams carrying loads of certain weights should have tires of a certain width.

In superintending the Park here in 1870 to 1876, I had great difficulty in preventing newly made macadamized roads from being cut to pieces by heavy teams going out to the acid factory, powder works, and certain other establishments beyond, there being no other line of communication except through the Park. I recommended the Park Commissioners to pass an ordinance providing that those teams carrying such and such loads (I have forgotten just what the loads were), should have suitable and proportionate width of tire. The ordinance was passed, and for a number of years heavy teaming was carried on without injury to the roads. I came to the conclusion that a five-inch tire put on a macadam road would do about one-tenth the damage that a three-inch did; certainly not over one-fifth.

I think if there were such an ordinance here in the city, it would be productive of great good. I know it is very much less draft on the horses on a roadway with a yielding surface, to have a wide tire than a narrow one.

In regard to foundation, there seems to be a great deal of misunderstanding on that subject in this city. The argument has been frequently advanced before the Board of Supervisors, that there is no foundation better than sand. That broad assertion is continually made, and they will say, "Go and ask any engineer, and he will tell you there is no foundation better than sand." Under certain conditions that is a fact. If the sand is boxed in, and you impose upon it an absolutely unyielding surface to press with, then that foundation is good—it is

just as good as rock. But if you put upon it a surface like a roadway, that may go down in one place and rise up in another, then the sand foundation is good for nothing. For some purposes, perhaps, it is true there is no foundation better than sand; but as a foundation for roadways it is not good, not near as good as rock, and not near as good as clay, if you drain the clay. Sand is not a proper foundation on which to lay this bituminous rock, as is frequently done here. We will never have good bituminous surface until we have a better method of laying it—a good thick bed of good concrete for a foundation.

Mr. Vischer has spoken of the utility of discussion on this matter. It seems to me that the utility of such discussions is to give the public the idea that engineers should have and do have something other than mere surveying experience. A very large proportion of tax payers of this country look upon an engineer as a surveyor, and nothing more. The city engineer, they think, should run out the lines and set the grades, and there his function ceases. Until the people of the country are educated to a different idea of the functions of the civil engineer, we need never hope to have civil engineers in stronger positions in respect to public improvements than now. I don't know how we can get *en rapport* with the people unless we make ourselves heard through the meetings of the Technical Society, or some other way like that.

A Member—There is one piece of asphaltum or bituminous rock pavement in this city that I have watched for over ten years; I don't know what company laid it, or where the rock came from. It is on the corner of Eddy and Jones streets. Until that was cut up a year or two

ago for the purpose of laying in a gas-pipe, I think it stood without break and perfectly intact.

Mr. Vischer—Speaking of the width of tires, experiments have shown that there is a marked difference between the wear produced by a three-inch and a five-inch tire, while between that and a seven-inch tire there is very little difference.

Another important thing to be considered in connection with pavements is the construction of the vehicle itself. It makes a great difference whether the load is carried on springs, or upon a dead axle. Here in San Francisco our heaviest loads are carried without any springs at all. There are numerous things that enter into the subject which we have been discussing, which make it a very intricate, instead of a very simple matter. Hosts of experiments have been carried on in European countries, and there is a literature to itself on the subject. I doubt whether this Society would find time to discuss the subject in extenso.

Mr. Herrmann—A law was passed about 1874 regulating the width of tires, which I believe was declared unconstitutional by the Supreme Court. The width of tire is an important factor in the preservation of good roads, and so also is the width of the wagon. With wagons of the same width, the wheels wear continuously in the same ruts, and the utter destruction of the road surface is only a question of a short time.

There was a law in Germany, when all freighting was done by horse-power, that a tire, I think ten inches wide, went scott free over the toll roads, no matter how heavy the load, or how many horses, but a narrow tire had to pay a heavy toll.

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HALL'S HYDRO-STEAM ELEVATOR.

BY R. HINCHLIFFE, MEM. TECH. SOC. P. C.

[Read May 1, 1891.]

The transformation that has taken place in the construction of elevators, since their general introduction into buildings only a few years ago, has been very marked. The best type in use about twenty-five years ago was the worm and wheel. These proved altogether too slow for rapid communication between the floors of high buildings. Various modifications were made until the introduction of hydraulics.

It is not to be understood from this that hydraulic cylinders for elevator purposes were unknown at the period referred to, but that they were so slow and cumbersome as to be totally inadequate to supply the wants of elevators of the present day. Although the worm and wheel proved a safe method, it was found impracticable to increase the speed necessary to meet the requirements of high buildings, and attention was turned to the improvement of hydraulic cylinders. Several enterprising firms took up the matter, and, after some experimenting, it was found that by storing water in an accumulator—*i. e.*, a vessel of sufficient capacity to hold water under

pressure—or a tank situated on the roof or other place sufficiently elevated, afforded a means of obtaining a regular supply of water to meet the requirements.

In many cases the cylinders of elevators were supplied direct from the water mains. This proved expensive, and to-day the majority of buildings use water under pressure supplied from tanks into which the water is pumped by engines on the premises. The plant necessary for this purpose consists of boilers, engines, pumps and tanks. The engine and pump are usually united into one machine. In this form the engine cannot be applied to any other purpose than pumping. The whole of the above plant, in all cases, has to be equal in capacity to lift the maximum load taken up by the elevator. And this is the principal defect in the system, that no matter what the load to be lifted, the expense is the same, because it costs just as much, in first cost and running expenses, to keep the tank or accumulator filled, and just as much water is required to fill the cylinders and lift the cage, whether filled or empty.

From observations of the writer, not more than one-sixth of the maximum load is lifted by elevators in every day working. So that the boilers, engines and pumps cost six times as much and the running expenses are six times greater than is demanded by the actual work performed.

A few years ago, Mr. Hall, a practical mechanic, was asked by his employers if he could not devise some cheap and easy means of raising and lowering loads in their building, without the expense of special pumps and tanks. After some consideration it occurred to him to try and apply directly the pressure in the boiler. His first idea was to lift the elevator by the water in the boiler with the pressure of steam on top ; but this was

abandoned as he saw no means of getting the water back into the boiler. It then occurred to him to apply the steam on the top of a column of water. To accomplish this it was necessary only to make such arrangements of pipes and valves as would enable him to apply the steam, and after the elevator was raised to the desired height, to exhaust it into the atmosphere as is done from a high pressure engine. This was soon accomplished, and the results were so satisfactory that he applied for and obtained letters patent.

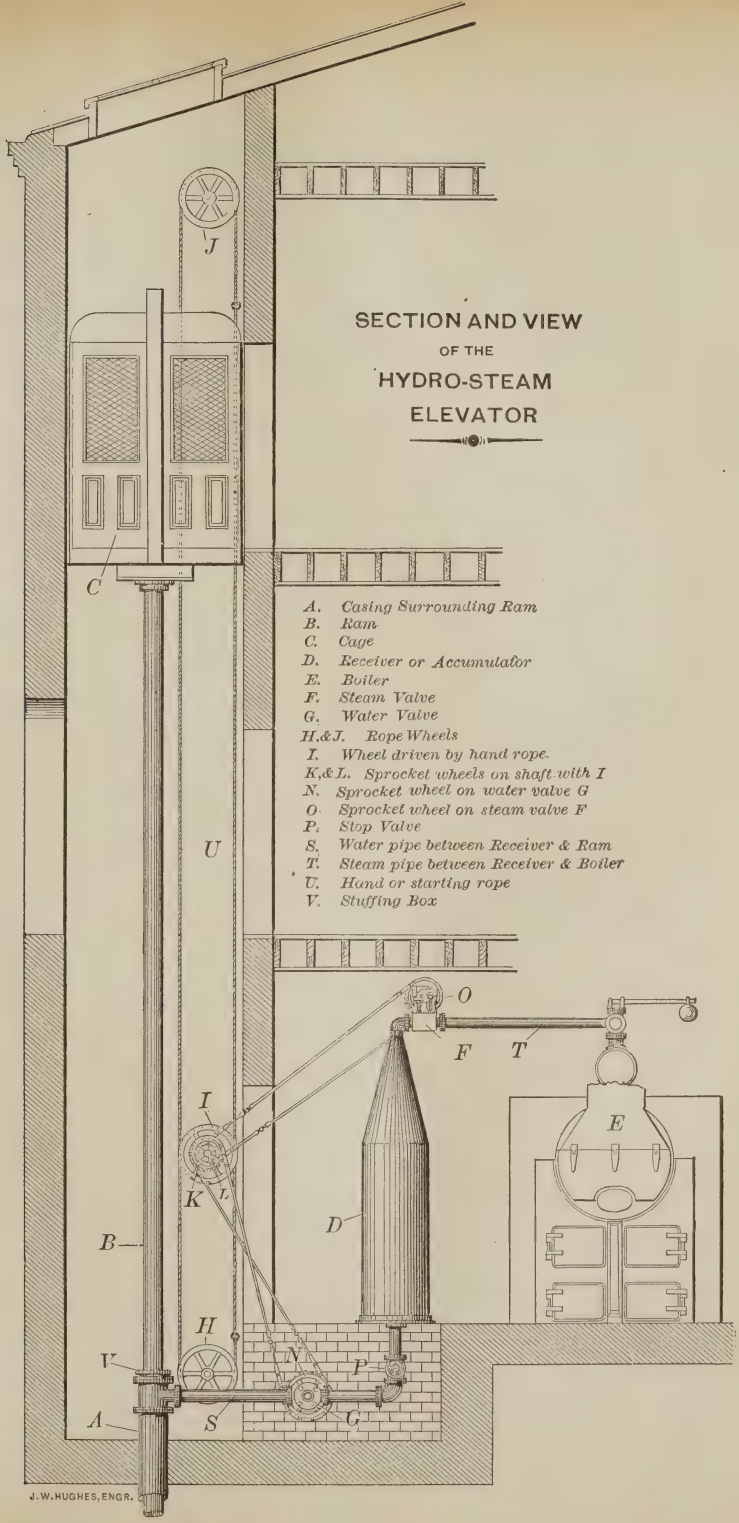
He had to overcome a strong prejudice in his own mind, and one that is very common, that steam would condense so rapidly when in contact with cold water, that its direct application, by contact, to a column of cold water to set that water in motion, was impracticable. His first attempts in this direction were partial failures because the steam did condense so rapidly as to require an enormous quantity, quite out of proportion to the work done. A consideration of the construction of the pulsometer led him to so modify the shape of the end of the receiver where steam was applied, as soon enabled him to overcome the rapid condensation, and finally to produce the present simple and economic method of raising elevators, which he has termed Hydro-Steam.

The great and primary difficulty was to apply steam to a column of water without agitating it. This was done by making the end of the receiver conical, sloping each side at an angle of 15 degrees. It could have been done, but not so economically, by using a column of water the same size as the steam pipe, but it was impracticable on account of the great length necessary in the case of a high lift. His object was to obtain a receiver of the requisite capacity of moderate length. The dis-

covery of the application of steam to a circular column of water sloping at an angle of 15 degrees enabled him to make a vessel of any desired capacity.

The next consideration was to devise suitable valves, to apply the steam, to control the water raising the elevator, to shut off the steam, to exhaust it, and finally to return the water to the receiver and at the same time to maintain perfect control over the cage. This was accomplished by two valves, one for the steam and the other for the water. In the diagram *A* is the iron case sunk in the ground in which the ram *B* rises and sinks. *C* is the elevator. *D* is the receiver which contains the water acted upon by the steam from the boiler *E*. The steam flows through the valve *F* into the receiver, and the water in the latter is set in motion by the pressure of the steam and made to flow through the water valve *G*, of which a full size section is likewise shown. The water, having motion imparted to it by the steam, enters the case *A* and raises the ram *B*. *H* and *I* are grooved wheels at bottom and top of elevator-well for holding the hand rope *U* in position. Said rope makes one or two turns round the wheel *I* and gives motion to it. On the same shaft with *I* are keyed two sprocket wheels *K* and *L*, which communicate motion through the chains and rods, respectively, to the sprocket wheels *N*, which actuates the water valve *G*, and *O* which actuates the steam valve *F*. *T* is the steam pipe connecting the boiler *E* with receiver *D*. *S* is the water pipe connecting the receiver with the ram, through the surrounding case *A*. *P* is a stop valve for shutting off communication between receiver and case, and *V* is a stuffing box or gland for keeping the ram *B* water tight in the case *A*.

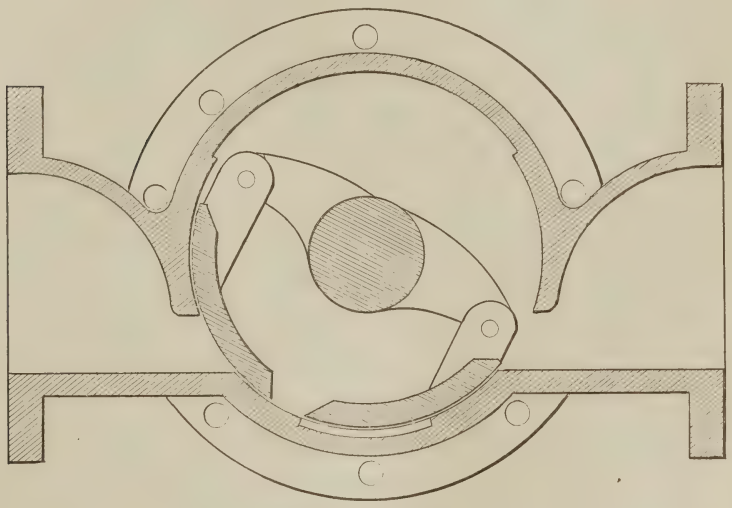
The steam valve is really two valves known technically


SECTION AND VIEW
OF THE
HYDRO-STEAM
ELEVATOR
A. Casing Surrounding Ram
B. Ram
C. Cage
D. Receiver or Accumulator
E. Boiler
F. Steam Valve
G. Water Valve
H.&J. Rope Wheels
I. Wheel driven by hand rope.
K,&L. Sprocket wheels on shaft with I
N. Sprocket wheel on water valve G
O Sprocket wheel on steam valve F
P. Stop Valve
S. Water pipe between Receiver & Ram
T. Steam pipe between Receiver & Boiler
U. Hand or starting rope
V. Stuffing Box
J
C
U
O
F
T
E
I
K
L
D
B
H
V
N
P
A
S
G
J. W. HUGHES, ENGR.

as the poppet type. They are similar in action to the common safety valve, with this difference: that the pressure of the steam keeps them closed. They perform four distinct functions, although only a double or two-way valve. One poppet allows the steam to enter the receiver and then shuts it off. The other opens to the atmosphere and allows the steam, after it has done its work, to exhaust, and then closes and prevents the live steam from escaping while on its way to the receiver. The two valves are controlled by a pin projecting from each side of a small circular disc, acting on a slotted lever attached to each valve, to which motion is communicated through a sprocket wheel keyed upon the disc shaft, acted upon by a chain from the wheel turned in the usual way by the elevator or attendant, and alternately opened and closed by the alternate motion of the cage. It is impossible to open both valves at the same time. When the elevator is at rest both valves are always closed. If the cage is to ascend by pulling the elevator rope in the proper direction, the steam valve is opened and allows steam to enter the receiver. If it is to descend, the exhaust is opened and permits the steam to escape. If the cage is raised to any point and allowed to stand during such an interval as permits the steam used to condense, on pulling the rope to descend, the exhaust valve is opened as usual and acts precisely as if the steam were to be exhausted. As there are two distinct valves it is to be remembered that the steam valve can only be opened on the cage ascending, and the exhaust on the cage descending. The mechanism is so simple that it is impossible for the valves to be moved the wrong way.

As the steam valve is placed between the boiler and the receiver, so is the water valve between the receiver

and the hydraulic cylinder. Like the steam valve the water valve is two distinct valves. The valve chamber is a hollow cylinder which can be made any diameter and any length, with an opening on each side, below the center, for the ingress and egress of water. A double rocking arm, with a joint at each end in line with the center, is placed in the cylinder, on a shaft, which passes through the covers. To each arm is attached, by the joint, a circular valve, which is machine



WATER VALVE.

ground to fit accurately the annular face of the chamber. Each valve is more than twice the length, circumferentially, of the openings in the chamber already mentioned. On turning the shaft either valve can be moved in a downward direction so as to completely uncover a port. But as each valve is more than twice the length of the port opening, both ports cannot be uncovered at the same time. If the pressure is less on the uncovered port than on the other, the water lifts the valve on its

hinge and passes through. If the pressure is greater on the open port side, the water cannot pass through in that direction so long as the valve covers the port. When the rocking arm is turned so that both ports are covered the water cannot pass either way but is held fixed in the position where the elevator stops. It is thus seen that the water valve controls the motion of the water exactly in the same manner that the steam valve controls the steam. The water valve is acted upon directly by a sprocket wheel keyed to the rocking arm shaft to which alternate motion is given in the same manner and at the same time as the steam valve. To give motion upward to the cage, both steam and water valves must be acted upon simultaneously. If the steam valve is disconnected from the elevator rope, the cage could descend by giving egress to the water through the water valve, but it could not ascend. And the cage in such a case could not descend if the valve were turned to take water from the receiver, as the port would be covered in that direction, so that the water could not escape. It is thus seen that the motion of the cage is perfectly under control, and that motion, either up or down, can only be given by moving both valves simultaneously in the proper direction. The manner of giving motion to the cage of the hall is exactly like that of any other elevator.

The speed is regulated by the size of water pipe, and can be adjusted to meet any requirements. As the receiver is placed close to the ram, only a few feet of water piping is needed. The steam pipe is common to both systems. No engines and pumps are required for this system. As the receiver is close to the cage the double system of piping necessary in the ordinary hydraulic elevator, up from the pump to the tank and thence to

the elevator, is not required. The running expenses are reduced to a minimum because the steam used in the boiler is proportionate to the work done. The cage can be balanced within a small percentage of its weight, therefore steam is wasted in overcoming the remaining small amount of dead weight only, and not in raising water to a constant height at the top of the building, no matter what the load, as is the case with the common hydraulic system.

To test the merits of the two systems, a trial was made at the California Electric Light Works on March 10th, 1891. The steam pump used on this occasion was a new one called the Buffalo pump, and is the outcome of the expired patents of the Worthington. Like it the Buffalo is a duplex, substantially made, and is similar but simpler in construction. The steam cylinder is 7½ inches diameter, and the water cylinder 4½ inches, with 10-inch stroke. It is exactly like the Worthington in action; the piston rod of one cylinder operating the valve of the other.

The following is from notes taken at the trial, which was witnessed by several members of the Technical Society of this city, and a few other gentlemen who are thinking of purchasing elevators.

After connection was made between the pump and the elevator, communication was closed between them by means of a valve, and steam was turned on. A pressure of 200 pounds was indicated on a gauge attached to the water pipe, when a small leak was discovered where the gauge was connected. After this was remedied the water gauge indicated 210 pounds. Steam was then shut off when the pressure went down to 195 pounds in three minutes, then down to 185 pounds in another ninety seconds, and finally to 180 pounds in another

ninety seconds. To sum the result, the pressure fell from 210 pounds to 180 pounds in six minutes, which quite satisfied the observers that the pump was in excellent order. A 100 gallon cask was filled up within a few inches of the top, into which was inserted the exhaust pipes from both pump and receiver. Their ends reached within a foot of the bottom and the pipes rested on props so that no portion of their weight was upon the cask. The receiver was a wrought iron cylinder, six feet six inches long, with a conical end next to steam pipe as described above, standing on end, and is 20 inches internal diameter. The cage is raised by a ram 8½ inches diameter, and has a lift of 31 feet 10 inches. The ram is made of standard steam pipe, and when turned true in a lathe is about ⅜ inch thick. It is enclosed in an iron case sunk into the ground and is in no way protected from the cooling effect of the earth surrounding it.

It may be here stated, parenthetically, that an iron column 60 feet long, 8½ inches diameter and ⅛ inch thick will support a load, including its own weight, of 14,800 pounds, with a factor of safety of 5. The same column ¼ inch thick will support 29,100 pounds with the same factor of safety.

The cage was now raised some feet from the ground and steam shut off from the boiler, which had the effect of preventing the cage from rising but not from coming down. No jerks or sudden starts were felt. The motion was easy and gradual just like the best regulated elevators. The cage remained stationary when the valve was opened from receiver, showing that complete control was exercised over it, and when the water sustaining the cage was allowed to run out, the cage came down in the usual manner. Steam was again turned on and the cage was lifted through its entire height in 10

seconds from the time of opening valve to automatically stopping. The downward trip was made in 11 seconds.

Communication with receiver to ordinary exhaust outlet was now closed and that from exhaust valve to cask, resting on platform scales, opened. Cold water was now run into receiver until it overflowed into cask, through exhaust valve, which was determined by scales showing increased weight in cask. Weighings of condensed steam now began, initial weight being 740 pounds; first trip, 749; second, 759½. This was considered excessive, a leak being suspected between barrel of cold water, to which pump was connected, and receiver, through a valve shutting off communication between them. The pipe was consequently disconnected. First trial was now begun, scale indicating 780 pounds. First trip, 789 pounds; second, 800½; third, 814; fourth, 823; fifth, 834; sixth, 842½; seventh, 853; eighth, 862; ninth, 870½; tenth, 873½; eleventh, 878; twelfth, 885; thirteenth, 893½, and fourteenth, 905 pounds; average, 8.8 pounds. This was considered excessive. The cage was now loaded with 2,255 pounds of iron, and second trial was made. Initial weight, 569 pounds; first trip, 570 pounds; second, 586; third, 595½; fourth, 606; fifth, 615; sixth, 623; seventh, 631; eighth, 640; ninth, 648, and tenth, 656; average, 8.7.

Two persons then got into the cage whose united weight increased the load to 2,617 pounds, and were carried up in fifteen seconds.

Steam was then shut off from receiver and trials with pump began. Steam was turned on and condensation was blown into the cask. Load same as before. Initial weight, 763 pounds. First trip, 774 pounds; second, 784. The condensation from these two trips was made into the cask in addition to that from receiver. The

cask was now emptied and re-filled with cold water. Condensation again blown out of cylinder. Third trial, initial weight, 604 lbs. First trip, 625; second $635\frac{1}{2}$; third, $648\frac{1}{2}$; fourth, 659. Average, $13\frac{3}{4}$ pounds. Time of trip, 52 seconds.

Cask was again emptied and re-filled, considerable water being lost by evaporation. Condensation again blown out. Fourth trial, initial weight, $710\frac{1}{2}$ pounds. First trip, $728\frac{1}{2}$; second and third, 756. Average $15\frac{1}{6}$ pounds. Cask again emptied as the temperature was over 150 degrees. Water in cask at next trial stood at 70 degrees, before blowing condensation into it, which raised it to 80 degrees. Fifth trial, initial weight, 809 pounds. First trip, $325\frac{1}{2}$ (tem. 98 degrees); second, 836 (tem. 108); third, 848 (tem. 128); average 13 pounds. Cask refilled with cold water. Initial temperature, 84 degrees, final 132 degrees. Sixth trial initial weight, 810 pounds. At end of three trips, $848\frac{1}{2}$ pounds. Average, 12.83 pounds.

The pump was now disconnected and the steam pipe attached to receiver. Seventh trial, initial temperature of water, 79 degrees, scale, 739 pounds. First trip, $751\frac{1}{2}$; second, $762\frac{1}{2}$; third, $773\frac{1}{2}$ (tem. 92); fourth, 785; fifth, $795\frac{1}{2}$; sixth, $805\frac{1}{2}$; seventh, 817 (tem. 102); eighth, $826\frac{1}{2}$. ninth, 836; tenth, 846; final temperature, 102 degrees; Average, 10.7 pounds.

A final trial was made with the cage empty with the following result: Eighth trial, initial temperature, 103 degrees; scale, 720 pounds. First trip, 725; second, $731\frac{1}{2}$; sixth, $749\frac{1}{2}$; seventh, 760; eighth, 766; ninth, $770\frac{1}{2}$; tenth, 776 pounds. Temperature, 125 degrees. Average, 5.6 pounds. The temperature of the water was then tested as it flowed direct from top of receiver and was found to be 185 degrees.

The results, for purpose of comparison, are tabulated:—

1st trial	steam,	cage	empty,	average	8.8	lbs.
2d "	"	"	loaded,	"	8.7	"
3d "	pump	"	"	"	$13\frac{3}{4}$	"
4th "	"	"	"	"	$15\frac{1}{6}$	"
5th "	"	"	"	"	13	"
6th "	"	"	"	"	12.83	"
7th "	steam	"	"	"	10.7	"
8th "	"	"	empty	"	5.6	"

It is to be noticed that in the first trial the average was 8.8 pounds condensed water from steam acting upon column of water in receiver. The water was cooler than in second trial, and although cage was loaded with 2,255 pounds, the average was only 8.7 pounds. The third trial with pump showed an average of 13.75 pounds, and in the sixth it fell to 12.83 pounds. In the seventh trial the water in receiver had cooled down during trials with pump and the average was consequently high. In the eighth and final trial the receiver had become warmed, and with the cage empty the average fell to 5.6 pounds.

Taking the minimum and maximum averages between pump and steam in the sixth and seventh trials, the difference is 20% in favor of the Hall system. If a general average is taken of the four trials with the pump and the four with steam, the difference is 61% in favor of the Hall.

It is to be borne in mind that in these competitive trials the pump was the most favorably situated as compared with ordinary practice because there was not a pound of water pumped that did not do full duty under the ram. The time required for the pump to raise the elevator through its 31 feet 10 inches of lift, loaded, working at 60 double strokes per minute, was 55 seconds.

The following deductions seem to flow as a matter of course.

First, That the Hydro-Steam system is cheaper to work by at least 50%, and,

Second, That this system is equally as safe and quite as much under control as the best hydraulic system known to the writer.

Third, That a horizontal or vertical cylinder, jacketed to prevent loss by radiation, with a multiple rope, would be a much more economical method, and fully as cheap as the ram and case.

The amount of displacement of a column 31 feet 10 inches long and 8½ inches diameter is equal to 12.4 cubic feet. The working pressure necessary to raise the cage loaded as above was observed to be 70 pounds per square inch as indicated by an Ashcroft gauge graduated to single pounds. Now, steam at 70 pounds above the atmosphere is equal to 5.4 absolute pressures. One cubic inch of water converted into steam at atmospheric pressure is equivalent to 1645 cubic inches of steam.

In this article it is called one cubic foot for the sake of simplicity. The error is about one twenty-fourth, so that it is not a serious one. As the quantity of water in steam is proportionate to the pressure, one cubic foot of steam at 5.4 atmospheres contains that number of cubic inches, and 12.4 cubic feet will therefore contain about 69 cubic inches of water, which equals about 2.5 pounds. If 9 pounds is taken as the average condensation for each trip of the elevator, loaded, more than 2.5 times of the theoretical amount required is condensed in the receiver, and yet, as is shown above, the Hall is from 20 % to 60 % more economical than the pump is under the most favorable circumstances. As ordinary coal will convert about 6 pounds of water into steam, each trip of the elevator, at that rate, would consume 1½ pounds.

As horse power is the product of mass into velocity, and as the load and cage are about equal to 3,750 pounds moving with a velocity of 3 feet per second, the work done in raising the loaded elevator through 32 feet represents 20 horse power, *i. e.*, if the cage were kept moving upwards constantly with its load of 2,255 pounds, a 20-horse power boiler would be required. As, however, one trip per minute is more than could be accomplished in actual work, it follows that 3-horse power per elevator would be ample to supply all demands where several elevators would be worked from one boiler. This is what Mr. Hall has found is required in practice. It follows that the more elevators are operated from one source of supply, the more economical would they prove.

In conclusion, the writer wishes to say that he began to investigate the Hall Hydro-Steam system several months ago, and the more he inquires into it the more he is impressed with its economy and utility as compared with other systems.

TECHNICAL SOCIETY OF THE PACIFIC COAST.

INSTITUTED APRIL, 1884.

TRANSACTIONS.

NOTE —This Society is not responsible, as a body, for the statements and opinions advanced in any of its publications.

(VOLUME VIII. No. 1.)

ABRASIVE PROCESSES IN THE MECHANIC ARTS.

BY JOHN RICHARDS, MEM. TECH. SOC. P. C.

[Read February 6th, 1891.]

In converting material by the various manipulative processes, nearly all relate to shaping and fitting—reducing to true or exact dimensions it may be called, and these processes for all kinds of material are mainly cutting, if we include in that term abrasive action, as well as that of edges or the "cleaving wedge."

This, of course, applies to finishing processes in which material is treated at its normal temperature, and not to what may be called hot processes, in which various kinds of material are melted and flow into form by gravity, or is softened and rendered plastic by heat so as to be pressed or hammered into form.

These last named processes, when applied to metals, are inexact, because the material is treated when in an expanded and distorted form. They are preliminary processes that have to be followed by either abrasive or direct cutting, to produce exact dimensions, so that nearly all material of every kind except that class called fibrous, is treated by cutting, either direct or abrasive, the latter being only a modification of the former, but

done under conditions that make it seem totally different.

In the conversion of wood, for example, calling for hundreds of various processes and implements, nearly all operations are direct cutting by means of edges; bending and polishing being the only exceptions in common practice. This is because the material is soft, and we find the same rule in horn, bone, leather, and indeed all material that can be so treated.

It is not the intention to generalize the processes of converting material. The subject is interesting and admits of classification in a great degree, as was shown by Babbage in his "Economy of Manufactures," published in 1832. The limits of a paper such as this does not permit notice of more than one branch or one division, if followed out to the circumstances of application.

Cutting, as before explained, is divided into two classes, direct and abrasive. The direct process by means of edges, applicable to soft material, and abrasive cutting, applicable to hard material. It is difficult to determine which of these is most extensive or important.

In some branches, machine fitting for example, the leading processes are direct cutting, this term applying to turning, planing, drilling, milling, and so on. In other branches, such as saw and edge-tool making, the principal finishing processes are abrasive by grinding on wet stones, or dry wheels, usually both, the distinction arising as before pointed out, by the hardness of the material and the accuracy required.

WET STONE GRINDING.

Abrasive cutting is performed by means of wet stones, sand, emery, glass corundum, crocus, rouge, chilled globules of iron, and in some cases by soft, friable iron

alone. Chief among these methods, is that of wet stones or common grindstones, which form a more important part of converting implements than is commonly supposed.

It is common to consider a grindstone as a kind of simple contrivance for rough work, not involving any operative conditions worth considering, but this is a great mistake. It is true that in sharpening tools and other operations where an indefinite amount is cut away and the material is held in the hands, all applied by yielding pressure, the operation is simple enough, but as soon as gauge or positive grinding is attempted we have a totally different process, one involving intricate and difficult conditions that a century of endeavor has not put into a scientific or even understood form.

In proof of this let me point out that if a wet stone grinding machine for exact dimensions is wanted, there is, perhaps, not a firm in Europe or America where such a machine can be ordered without supplying plans for it, nor is there, outside of the factories where such machines are developed, any knowledge of the processes that will permit the construction of such machines, and it is because of this fact mainly I have brought the subject of grindstones before you this evening.

Before proceeding to consider gauge grinding machines it will be proper to mention that they are not exceptional. Saws of all kinds from the tiny web, one-eighth of an inch wide, up to the huge circular saw, six feet in diameter, are all gauge ground by machinery on wet stones. Some of these machines cost many thousands of dollars, and on this process more than any other does our modern manufacturer of saws depend. Carpenters' steel squares, files of all kinds, smoothing irons, spindles, gun barrels, and in some cases small shafts, are *gauge*

ground. The nearest organized manufacturer of gauge grinding machines I have known was a works that existed twenty years ago at Cohoes, New York, where an ingenious mechanic, by the name of Blake, constructed wet stone machines for various kinds of work. I visited his works in 1865 when he was engaged in constructing machines for grinding files, squares, and other kinds of tools, the purpose of my visit being to procure machinery for grinding plane irons at the Ohio Tool Co.'s Works, where I was at that time engaged, and I must say that so far as appears, the main problems involved in these processes and the means of meeting them were then as well understood as they are now. It is true that since that time, and especially during the ten years that succeeded, Mr. Baker, of the Disston Works in Philadelphia, developed a great deal that was new in grinding, discovering certain rules or principles that in some degree gave promise of a more scientific understanding of the processes.

Mr. Baker, who is better known here as the inventor of the blowing machines that bear his name, is perhaps the greatest expert now living in the art of wet grinding. He is also a mechanic of eminence in many other branches, but wet stone grinding he claims has presented the most difficult problem he has met with in the great Disston Works at Philadelphia, Pa., and in another large works of an analogous kind where he is now engaged, if living.

Mr. Blake, before mentioned, removed to England, where I am informed he now carries on an extensive business in grinding for the trade. His method consisted of an endless platen or chain of platens, revolving in front of the stones, the plates or tables being guided as they passed the point of contact, so as to

present the pieces in various positions, they being fastened on the plates by means of clamps. The difficulty encountered, and the main one presented in all kinds of wet stone grinding, was the rapid wear of all rubbing or running parts.

The endless platen method has gone out of use unless yet practiced by Mr. Blake himself, and present methods are by means of carriages mounted on wheels, the axle bearings of which can be protected, and by means of radius frames that swing from a pivot. This latter is applicable to forms of any kind that can be bent to suit the curve and thus be ground parallel.

I will now proceed to notice some of the conditions of gauge grinding by wet stones.

First may be mentioned the arc in contact. This cannot well exceed three-eighths of an inch, even for large stones, and where there is a flood of water. This may seem a strange proposition, but is the rule adopted by Mr. Baker, and is fully confirmed by my own experience. It is true that a plane, meeting a circle, presents but a point of contact, but even a small film cut away, as the work is moved along, presents this amount of contact, especially with large stones, and as soon as that area is exceeded, water is excluded, the pores of the stone fill with metal, the work is heated and either spoiled or "pulled" out of the machine.

In a machine I constructed about 1886, using stones six to seven feet diameter and twelve inches thick, consuming forty horse power to each stone, we frequently threw the pieces out by heating. Plane irons two to three inches wide, averaging one-fourth of an inch in thickness, would be curled up like a wood shaving, turned blue, and fired into a wall like projectiles from a gun.

As a rule, the narrower the line of contact the better, hence the radius carriages that present a curved surface opposed to that of the stone, work best for thin, flexible pieces.

About the same time, before mentioned, I constructed another machine of smaller size for billet web saws, in which the pieces were fed through continuously, by means of rollers, and found that even with soft stones there was continued heating and danger, until a reversely curved bed was placed opposite to the stone so as to reduce the arc in contact, which in that case could not much exceed three-sixteenth of an inch.

The difficulty in such cases is either the absence of water or else the filling of the interstices of the stone. It is difficut to tell which; in fact, as before remarked, the whole process is a mystery as far as observation can go. One has to deal with "symptoms."

A second condition is the element of elasticity. What this has to do with grinding is by no means clear, but it is an essential feature. I mean moderate elasticity, because any yielding that would permit a stone to wear out of "truth" would spoil all.

In the large machine first mentioned for grinding plane irons, the bed or carriage was eight feet long and sixteen inches wide. It was of iron, about four inches thick, and with its mounting weighed over a ton. It was moved by rack and pinion gearing placed in a room separate from the machine, to preserve the machinery from grit. The platen received eighty common plane irons, laid with steel on one side, and tempered hard. The first experiments were discouraging, but it was soon found that a pine board one inch thick placed between the table and the work prevented difficulty, unless the stones were too hard.

In most cases the elasticity due to wood framing, or tables mounted at the ends only, is enough, but there must be elasticity from some source.

The third condition I will notice is the hardness of stones. A hard stone cannot be used at all for gauge grinding, and the softer a stone is the better it will work; but there is a commercial limit in the case, because soft stones soon wear out. The advantages of a soft stone I conceive to be in the fact that the rapid wear presents continually new and sharp edges; also the water saturation because of porosity is more complete. The function of continued waste or wear will be further noticed in connection with emery wheels or corundum wheels.

There are many cases where gauge grinding with stones has been attempted and abandoned, after expensive experiments, because the stones used were too hard or too fine. Indeed most of the difficulties that have come under notice have been due to this cause. In some cases a lack of water has been the cause of failure. It is not enough to flood a stone with water, especially one running at high speed. The water must be shot in by a jet between the stone and the work and distributed all the way across the face. The agency of the water is to carry off the heat and also to wash out the sand and particles of metal cut away.

The principal development of wet stone grinding, that is, gauge grinding, has been in the large saw manufactories and also tool factories. I do not mean hand grinding. That is simple enough and calls for no notice, but gauge grinding has been the subject of a great amount of ingenious effort in these manufactures by highly skilled mechanics who have not carried their knowledge beyond the works where it was applied. What inventions have arisen in late years I am not able to

say, but the conditions before noted must apply to all of them, whatever they may be.

In England a good many cemented or manufactured stones or wheels are used for wet grinding. At the works of George Richards & Co., Manchester, such stones or wheels are used for grinding wrought iron pulleys, and a careful account of expense and time shows a saving over natural stones, although the latter are much cheaper in first cost.

The stones employed are at the beginning, about four feet in diameter and six inches thick. I am not aware of the kind of cementing material used in their manufacture, but it is in a limited degree soluble in water.

DRY STONE GRINDING.

Under this head I am not able to give you much information. There is but little dry grinding done in this country, and so far as known, only on stones brought here from England.

It may have been noticed that the shanks of tools brought from England, chisels for example, are ground crosswise and are very rough. This is done on small stones driven at high speed called "shank stones." They were formerly employed for the same purpose at the Barton Wool Works, in Rochester, New York.

Their operation is apparently the same as that of a coarse emery wheel, and the mystery is, that they do not "glaze" or fill with metal; but there is some peculiarity in their structure that keeps them clear. I imagine they would soon fill, if applied to gauge or positive grinding.

A stone, when glazed or filled, ceases cutting or abrading, and some kinds, granite, for example, are suitable for the bearings of shafts. I have myself seen in several cases in Sweden the main or water wheel shafts of

sawmills mounted in granite bearings, and in one case had a shaft lifted to examine the surfaces, which were polished and had a metallic appearance.

The tendency to "pull" as it is called in dry grinding or in common grinding, when a stone becomes too dry, is a phenomenon not easy of explanation. For example, if we have to turn off a grindstone, either in its manufacture or to make it true, in use, a hard or sharp implement is of no avail. It must, on the contrary, be of soft iron or steel and held in a dragging position on the face of the stone. A piece of common gas pipe is often used for this purpose.

When the tool takes hold, which it will not do unless the conditions are right, it will "hang on," tearing out a deep furrow and apparently cling to the stone. Only a blunt end is required, and, strange to say, complete elasticity is essential.

For this purpose it is common to use a steel rod, large enough to be held in the hands, five-eighth to three-fourth inches diameter, but the cutting end is drawn down to three-eighth inches square, a slender rod, which bends freely when it takes hold of the stone. All this, so far as is known, is unexplained phenomena, familiar to shop practice as a fact, but a mystery so far as the nature of the operation is concerned.

In this same connection, but not to anticipate what is to be said of rolling abrasion, I will mention another method or trueing or turning stone by means of rolling implements, that "force off" the material by pressure.

A small beveled wheel with a dull edge is presented to the face of the stone in a diagonal position, so as to rotate slowly with it, and is passed positively across the face, "spawling" off the irregularities, in pieces, at one operation. The same operation is the most successful

one for shaping stone by machinery, that has ever been invented, and will be treated upon in a future place.

Unless these facts suggest some explanation of why stones do not glaze or fill in dry grinding, I have none whatever to offer.

Dry grinding is not uncommon in England. Razors, for one thing, are dry ground, and I believe also many other implements of the kind that would be injured or destroyed by the heat which would naturally be supposed to result from that process.

ABRASIVE CUTTING BY HEAT.

Under this head not much is to be said. The operation consists in applying smooth discs of steel or iron, driven at high speed, to pieces to be cut; the heat developed by friction being sufficient to melt the metal in contact with the wheel, or what is more profitable, softening it to a plastic state, so it is rubbed or worn away by the wheel.

This operation has a place in what may be called the romance of processes. Most everyone has heard of it and wondered at it, but I imagine no one has ever seen any very useful function performed by this means.

In a tolerably wide observation of manipulative processes in this and some other countries, I have never seen this process but once applied in a manner or under circumstances that seemed necessary or economical, and that was in the U. S. Armory at Springfield, Mass., where it was employed in preparing a tenon, or reduced section, on the ends of tempered steel ramrods, such as were used in loading the muskets of twenty-five years ago.

The material was hard and could not be cut, so small wheels of iron about six inches in diameter and one inch thick were used. They were driven at six thousand

revolutions per minute and melted or abraded the metal away instantly, at the same time drawing the temper so that a screw thread could afterwards be cut on the end of the tempered rod.

My own experiments have been confined to cutting off small bars of round and square iron by means of discs twelve inches diameter of No. 16 gauge plate. The operation was slow, unsatisfactory, consumed a great deal of power, and left the surfaces with a hard scale that afterwards destroyed files or other tools.

I have also seen railway bars cut off by this method, the saws being about four feet in diameter and five-sixteenth of an inch thick; but so far as known all these operations have been supplanted by cold sawing with regular saws, having sharp teeth and cutting the same as a circular or band saw does in wood.

In respect to this last operation of cold sawing iron and steel, I will digress enough to say that it is a process of great importance, that has been at least ten years in making its way to this country. Five years ago there was scarcely a large engineering works in England that had not among its implements either circular or band-sawing machines for metal, and in many cases both.

Messrs. Cramp & Son, the shipbuilders at Philadelphia, three years ago ordered from England two of these cold saws for cutting off deck beams and other bars, and one is in use at the Union Iron Works in this city. The United States Government, about one year ago, ordered from a firm in Leeds, England, a band-sawing machine for cutting metal at the Washington Ordnance Works. I know of a works in England where there are fifteen such machines in constant use.

The manufacture of cold sawing machines has now been definitely commenced in Philadelphia, but it is a

tardy beginning, considering their extensive use abroad in England, Germany and France five years before.

ACCURATE GRINDING.

Grinding is the process of accuracy. I have explained how it was the only process of treating hard material, from tempered steel to the diamond, but an equally important function is the one of accuracy. Considering abrasive cutting as one of delicacy or precision, direct cutting is in comparison only a "roughing out" or preliminary process.

In metal working the operation of cutting has a limit of accuracy at one-hundredth part of an inch in coarse work and one two-hundreth part in fine work. I mean in common turning and planing. In grinding, the range of accuracy comes down to the ten-thousandth of an inch in common operations, and much less in the finer operations. All accurate and all polished surfaces are finished by abrasive operations, and after this statement it may be perceived how these processes are more important than cutting with edges.

In the manufacture of gauging implements of precision with which I was connected for many years, grinding processes opened up a new field. It was at the beginning of what may be called the emery wheel period, but involved a great deal more than common grinding processes, and a good deal that is never learned in any manufacture not involving dimensions within a five-thousandth part of an inch. I do not, however, propose to go into this matter here, having in view at some future time the presentation of a separate paper to the Society, on the manufacture of gauging implements. The purpose is at this time to explain, or comment, upon some of the phenomena that attend on accurate grinding by wheels.

The manufacture of emery grinding wheels as now carried on is not what it should be. A dozen or more companies are making and recommending their particular wheels as superior to all others, but as to how these wheels are cemented or made there is no knowledge whatever. As a matter of fact, there are certain kinds of cutting material and certain kinds of cementing material that are best for particular processes, and it is certainly time this were a matter of common knowledge among mechanics and manufacturers. The requirements demand a very wide range of quality in such wheels, and there should be something more reliable to depend upon than the trade secrets and circulars of makers.

This matter is illustrated in the attempts at accurate grinding before alluded to. Letters were written to the various makers of emery wheels, and I believe, without exception, each one had "precisely what was needed." The fact was, that no maker in the country knew what was required, and scores of wheels were tried and abandoned as soon as tried.

While these attempts are being made to grind caliper and other gauges, Prof. John E. Sweet, of Cornell University, came to the works, and as an act of disinterested kindness placed at our disposal the knowledge he had gained in several years of experiment in accurate grinding at the laboratory of Sibley College. This information, although valuable and expensive, was discouraging in the fact that his conclusions were that abrasive grinding could not be done without pressure, and with pressure accuracy was impossible except as a "trial" process.

Let me explain here that trial operations are not admissible in any organized process for the duplication of

work. One may "cut and try" and thus secure accurate dimensions, but this is not manufacture, in a commercial sense, for our time at least, and was not applicable to standard gauges. Implements so made would cost a great deal and would be of no commercial use for that reason. In the duplicating system of making small arms, for example, if any part is touched by a file or any implement that is hand guided, that piece is lost. It becomes special. In Geneva, twenty years ago, when watches were made by hand and trial fitted, such watches could not compete with those made here when the rate of wages was ten times as much as in Geneva. Trial work is of no use in the accurate fitting of any article to be reduced to a manufacture, so that Prof. Sweet's conclusions were discouraging. Thousands of dollars worth of gauges and machinery were made and lost at the gauge works, until light came from an unexpected source. I am speaking of twelve years ago.

Some years previous to that time J. Morton Poole, of Wilmington, Del., introduced a system of accurate grinding for calender rolls for paper making. These rolls, some of them seven feet in length, had to be made for rolling tissue paper, which will pile two to four thousand to an inch of thickness and variations of one ten-thousandth of an inch in diameter or alignment would distort the paper as it passed through the rolls. Mr. Poole had exhausted the emery wheel market as we had done, and ended by advertising here and in Europe for samples of emery and corundum. He collected such samples and established a laboratory for experiment and the manufacture of wheels, and, finally, after many failures, produced those that would grind without pressure.

This was done by cementing the wheels with sub-

stances soluble by soda water, using the sharpest corundum carefully assorted. When the wheels were at work a stream of alkaline water was run upon them, so the surface was continually but slowly melted away, and each time the wheels turned around, so to speak, new edges were presented to the work, and when the conditions were favorable the cutting went on without appreciable pressure. This was the lacking feature, and through his skill and kindness the gauge business succeeded.

Let me explain respecting pressure that the flexure and yielding of joints in the most carefully constructed machine, even under light pressure, is enough to destroy the accuracy of these processes, and also, as flexure is accompanied by heat, the distortion from that cause is a farther difficulty. The same rule applies in all accurate abrasive grinding and quite the reverse of what has been noted of wet stone grinding. Pressure always produces flexure and distortion. The Poole system of grinding, which should come next in order here, would make this paper too long, and I beg the privilege of supplementing it at some future time with a continuance of these remarks in which rolling abrasion, chilled iron sand, and the sand blast will be noticed.

SECOND PAPER.

ABRASIVE PROCESSES IN THE MECHANIC ARTS.

[Presented July 3, 1891.]

THE POOLE SYSTEM OF GRINDING CALENDER ROLLS.

It is with some regret that I am compelled to set up a precedent of a paper in two sections, but in the present case it would have been impossible in a single evening to have done more than merely mention the various processes that come under the head of "Abrasive Cutting in the Mechanic Arts."

Before entering upon the subjects treated in the present paper I desire to call your attention to the fact that the processes to be described are not only recent and distinct inventions, but are also extensively and permanently applied in the industrial arts. This claim is perhaps required to supplement or excuse description so compendious as to be imperfect, but it must be remembered that the best papers presented to a Society like this are "suggestive" instead of "exhaustive." My familiarity with the processes will enable me at the end to explain any points not made clear in the body of the paper.

In the former section I attempted to explain what the term "cutting" includes, as well as the nature of abrasive cutting so far as it is familiar, or can be understood, I shall therefore in the present case not occupy any time in explanation of the general subject, but will proceed to describe, as well as possible, one of the strangest processes that can be referred to—one without precedent, so far as mechanical literature will show, and one that has for twenty years remained confined to one purpose. I allude to the invention of J. Morton Poole, of Wilmington, Delaware, for grinding calender rolls.

That it can be made plain I much doubt. John W. Nystrom, the well known mechanical engineer, made a visit to Messrs. Poole's Works, in Wilmington, Delaware, soon after this process was inaugurated there, and after half a day spent in observing the machines at work, came away without understanding the process. On a second visit he "caught the idea," as he expressed it, and I have a similar confession to make respecting a total inability to comprehend at first the nature of the operation, and of a still greater diffculty in communicating it to others, by words or even drawings.

This I will now attempt, and at the end mention some more facts of an interesting kind connected with the process.

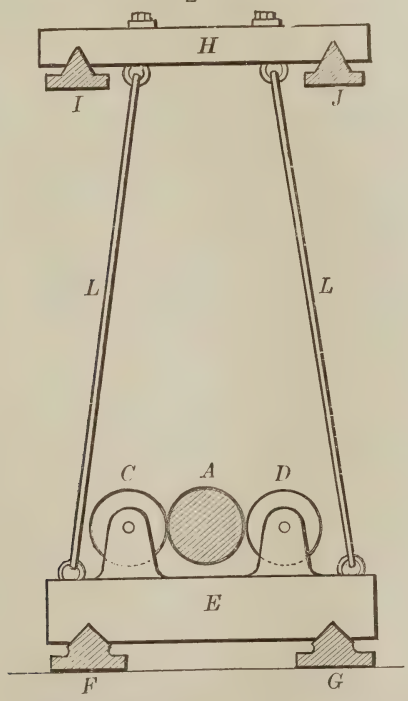
In the first place, I will say in respect to what are called calender rolls, that for certain purposes—paper-making for example—these rolls require an exactness scarcely attainable by the ordinary processes. They are sometimes seven or even eleven high, and are from five to seven feet long. Their accuracy in straightness and parallelism, should be within one five-thousandth part of an inch in their length or diameter.

Tissue paper, a common article of manufacture, will pile two to three thousand to an inch, and this must be uniformly gripped by the rolls as it passes through, and I am inclined to think that variations of one five-thousandth part of an inch would affect, if not destroy the web, because its thickness is no measure of a roll's variation. The paper will "draw" if it is gripped loosely at any part of the width of the web, that is, one portion will "overrun" another portion, if the grip is not uniform across the web; and I leave it to your imagination what the exactness of calender rolls must be to deal with paper piling two thousand to an inch. Even common

printing paper, Molesworth's Pocket-book, for example, has five hundred leaves to an inch.

A line of light is observable to one five-thousandth part of an inch; some claim one ten-thousandth, and yet a pile of calender rolls, eleven high, can be so ground by the Poole process, as not to show a line of light between them. You will wonder what becomes of flexure from gravity in such a case, but even that is provided for with the greatest exactness; but this I will not attempt to explain, as it involves apparatus that would extend the present paper beyond the limit intended.

Fig. A.



Referring to the Diagram **A**, let *A* be the roll to be ground, *C* and *D* grinding wheels, mounted on a carriage or platform *E*, which weighs a ton or more. *F* and *G*

are angular ways, on which the carriage *E* moves parallel to the roll *A*, which is mounted on its own journals at each end in strong stationary bearings, combined with the ways *F* and *G*.

Next suppose *H* to be a second sliding carriage, moving on the ways *I* and *J*, and the lower carriage *E*, suspended to the top one by the rods *L L;* also suppose the standards *M* and *N* to be adjustable on the carriage *E*, to and from the roll *A*, and you will be ready to consider the method of operating.

In the first operation we will consider the lower carriage *E*. The rolls being turned in what is called a "chill lathe," they are put into the grinding machine, and the wheels *C* and *D* are advanced to touch on each side and traversed from end to end of the roll. These wheels are driven at a high velocity and are flooded with soda-water. The roll *A* is also revolved at a slower speed, perhaps one hundred revolutions per minute.

The wheels *C* and *D*, being fixed in respect to the platform *E*, become in effect a calipering apparatus, producing precise parallelism in the roll *A*, as the carriage *E* is traversed along on the ways *F* and *G*. It is like passing the roll through a die. There is no opportunity whatever for irregularity in its diameter, but it will be seen that its straightness will depend on the alignment of the grinding ways *F* and *G*.

Now it may be thought that this is complete, and that carefully planed ways will produce true alignment, but this is not so. The work produced by a good planing machine is true enough for most purposes, but falls far short of the requirements here. If an absolutely true straight-edge is placed on the ways *F* and *G*, there would not only be a line of light, but deviations through which one could pass not only one, but several thicknesses of

tissue paper. This process does not produce truth of alignment and we now come to that. The roll *A*, being ground to exact diameter from end to end, the main carriage *E* is lifted from its ways and is suspended by the rods or links *L* to the carriage *H*. These links are on knife edges of hardened steel, and so nicely poised is the great mass of the carriage *E* that the slightest pressure will swing it. The adjustment of the wheels *C* and *D* is now made with little mallets of pine wood not weighing more than an ounce, poised on spring handles so the adjusting screws are struck slight blows, the same as a hammer acts on a forte-piano wire. This is necessary, because to touch the screws by hand would disturb the carriage *E*.

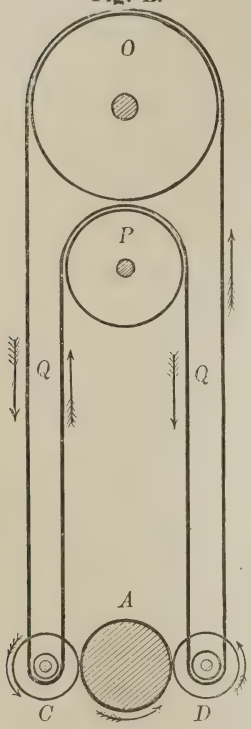
Now imagine the carriage *E*, suspended as described and traversing along on the ways *I* and *J*, at the top; the roll *A*, revolving at one hundred revolutions per minute and the problem of the Poole system is before you.

What will occur? is the question. The slightest amount of crookedness of the roll *A*, would swing the carriage *E*, from right to left at each revolution of the roll, but this is impossible because the mass weighing a ton or more cannot be moved one hundred times a minute from right to left; at the same time its method of suspension is such that a breath almost will move it if "time" is allowed. The truth of the ways *I* and *J* now becomes a matter of indifference because movement to the right or left of the carriage *E*, to compensate for truth in these ways calls for a force so minute as to be undiscernible.

The result is that the traverse alignment of the carriage is controlled by what may be called the axis of rotation in the roll itself—a kind of theoretical line, so perfect that the result is absolute straightness within a

ten-thousandth part of an inch in six feet, or even a less limit if there were means to prove it. It is a curious problem that has to work itself out in one's conception, and I imagine involves in some way the elements of what we call gyroscopic action, which I need not say has no explanation open to average conception.

Fig. B.



As the mechanical engineers present are no doubt wondering how motion can be imparted to the grinding wheels *C* and *D* without disturbing the carriage *E*, when it is swinging free, I have prepared a second diagram, **B**, which explains Mr. Poole's method for this.

The grinding wheels are driven by a true endless band *Q*, passing continuously around the pulleys of both grinding wheels as shown. *O* is the main driving pulley and *P* an idle one, made of such diameters that all four strands of the band are vertical. This exerts no disturbing force on the carriage so long as the band runs true.

This principle, or mode of operating, has not, so far as known, ever been applied before Mr. Poole's invention, and seems to have no function beyond the present process. So intricate is it that Mr. Morton Poole, the inventor, when he presented his drawings and description in Europe was at first laughed at and called a "crank." He, however, as he used to say, got it hammered into a Scotchman's head at Leith near Edinburgh, where a great many rolls have since been made by this

process. On the continent he met with better understanding of his mysterious process; in Germany, at least, where there is a large establishment employing such machines.

I had the honor to know J. Morton Poole intimately, and from my knowledge of the man and his habits of thought, have not the least doubt of his inventing this process by inductive and deductive reasoning. He was a type of a class of constructing engineers, very few in number, invested, as I have sometimes thought, with a strange power of discerning the mysteries of forces and the means of their direction, by a kind of intuition. I am the more impressed with this idea from the fact that when he was seventy years old he enabled my son and myself to overcome what seemed insuperable impediments in the manufacture of standard gauging implements. In ten minutes time he taught us more than a year of expensive experiment had brought to light.

When the present method of grinding straight and parallel occurred to him, he went to various paper makers and proposed that if they would furnish him in advance with the capital he required to construct his plant of machinery, he would grind and prepare their calender rolls for a term of years at a given price, much less than was then paid, and would also agree to tests which others, grinding by the lap process, would not dare to undertake. His proposal was acceded to and he proceeded to carry out the scheme by which he not only ground the rolls with greater truth than had hitherto been attained, but at a cost to him which I imagine was less than one-half of what it had been by the "lap" method. He died about six years ago, after adding much to what may be called the science of manipulation process.

ROLLING ABRASION.

I now come to what is the most novel and least known among abrasive processes—that of "rolling abrasion," that is, the disintegration of hard material by means of globular particles rolling under pressure.

This is a new process, in so far as entering into industrial use, and was the discovery of Messrs. B. C. & R. A. Tilghman of Philadelphia, the inventors of the sand blast, which will be explained in a future place in this paper. The sand blast experiments after they had progressed some years, led to what may be called general experiments in cutting and abrading obdurate material, such as hard steel, glass, granite, and so on.

The Tilghman Brothers had at Philadelphia an extensive laboratory, equipped with all kinds of apparatus for physical experiments, and in some attempts at cutting or abrading hard materials it was soon discovered that the ordinary agents, such as sand, corundum, glass and so on, had but little effect on tempered steel, glass, granite, flint, and the like. They also discovered that while the scratching or cutting of such material was slow and expensive it could be easily pulverized by means of pressure applied on a small point such as a sphere presents when in contact with a plane.

It will be a little difficult to conceive of a process for abrasion that is analogous to, or is indeed a counterpart of what are called ball-bearings, that run almost without friction, consequently without abrasion, but there is a degree of pressure that must be exceeded before abrasion begins, and ball-bearings will operate up to that limit. Beyond that they constitute the most effective means known of abrading the surfaces on which the balls roll, especially if the latter are hard and inelastic. But this matter aside, the discovery of the principle, to

so call it, of rolling abrasion, left the Tilghman Brothers very near where they started, because there was no means of making or procuring hard globular particles for abrasive cutting. They next set about the problem of producing a suitable substance, seleting cast iron, which when chilled is as hard, or harder than tempered steel. It was found that when cast iron in a melted state was divided fine enough to form a sand, or even in the form of what we call "shot," it burnt up instantly if exposed to the oxygen of the air; so the first experiments were made in a sealed room from which oxygen was excluded. This was a very difficult and expensive matter, because the room had to contain apparatus which was wholly inaccessible when in operation.

After years of expensive experiment, the Tilghman Brothers succeeded in producing the chilled cast iron globules, or shot, at a price which enabled the use of the material in sawing stone, grinding plate glass and analogous operations.

With this material, brownstone, marble or any of the softer kinds of stone, using the same machinery, will saw four times as fast as with sand by the common process. Granite which, previous to this invention, could scarcely be sawed at all at a cost commercially practicable, is now sawn by the aid of the globules ten times as fast as with sand. Not only this, the wear of saw blades is only one-fifth as much. More than two hundred and fifty firms are now using this material for sawing stone, and it has stood the test of nine years in practical use.

The stains due to corrosion, which at first seemed an impediment to the process for sawing white stone, is easily avoided by the use of lime in the water.

I am not privileged to describe the processes of manufacturing the iron sand or globules, further than to say

the metal is disintegrated or torn to pieces by the action of high pressure steam.

The firm at Philadelphia has courteously sent here eight samples of this chilled iron sand or shot, which is contained in the bottles present, labeled with the grade or fineness, the numbers employed being the same as designate the grades of emery.

After the very long and expensive experiments, the Tilghman Brothers succeeded in reducing the cost of the chilled iron shot to a commercial point where it could enter profitably into industrial processes, and now has reached a surprising cheapness. The price, as before said, is, for the finer grades, less than is charged for common machine castings here in San Francisco. The price of No. 30 to No. 40, delivered free, in one hundred pound bags, to railway or steamer, is 4 cents a pound; No. 40 to 60 is 3½ cents a pound. The coarser grades, which are more difficult to produce, are sold at 5½ cents a pound, and it is safe to suppose the manufacture is not likely to be introduced on this coast for a long time to come at least. There is but little wear in use. The consumption per month is only about forty pounds to each saw. The shot is washed out of the sludge and is used over and over again.

The fine particles, which, for the smallest numbers look like dust, are, nevertheless, well-shaped globules, the same as in the coarser sizes. This may be seen when they are magnified. Their efficiency depends on their rolling, consequently on how nearly spherical they are, and this shows the clear line that may be set up between abrasion by crystalline or irregularly formed particles, like sand or emery, and the spherical or rolling particles. The two are quite distinct in nature, and require very different methods. Any silicious substance

would be at once crushed by the circumstances under which these globules are used, for example, under the edges of thin loaded saws in sawing granite.

As before mentioned, until the discovery of this means of cutting granite, that material could only be sawn for special purposes, and sawing may be said to have been impracticable for any commercial purpose. The effect on various other industries has also been very marked, plate glass manufacture, for one.

I think it due to Messrs. B. C. & R. A. Tilghman to say here that this is not the only new industrial process they have given to the world. The distillation of glycerin, fat acids and other products of animal matter, by high temperature steam, is another of their inventions that has added millions to the useful products of this and other countries. This invention, made more than thirty years ago, and by which glycerin has been produced ever since, was in the United State courts for much longer than the life of the patents that covered it. The number of trials in the Circuit and Supreme courts I am unable to state, but the advantages of the invention were largely shared by the lawyers; and I am sure it is within bounds to say that Messrs. Tilghman spent not less than $100,000 in defending their invention of this distillation process.

Resuming the subject of the iron sand or shot, if one of these spheres, large or small, is rolled under pressure on a surface of glass or any other hard friable material it will leave a line of abrasion behind. On glass it will produce a white streak similar to, but not so deep, as a common score made by a diamond. The hardness of the material compared to other substances I am not able to state in definite terms, but, as a practical illustration, these spheres can be imbedded by pressure into untem-

pered steel. In comparing with emery corundum or silicious substances our mechanical friends can imagine a ball of chilled cast iron dropped into the crushing machinery employed to prepare such crystalline substances and the wreck that would follow. The only thing we can compare with it is the diamond, and I am not sure that the black carbons of commerce, if reduced to the same spherical form, would stand more pressure although their endurance of wear might be greater.

I have crowded into these remarks on the chilled iron sand or globules, matter that should form the subject of a long paper. The attempts to produce the sand, extending as they did over half a dozen years, would, of itself, be a narrative of great interest as well as value to the members, and regret that more can not be said of it now.

THE SAND BLAST.

There is perhaps no one present who has not heard of the sand blast. It was a distinct discovery in the processes of useful art and of exceeding novelty, which like many more had its origin in natural suggestions.

I will explain that it is an attritious wearing away by grains of sand blown forcibly against friable material. It is illustrative of the old saying that "continuous dripping wears a stone," but is infinitely more effective than that. The blows given during a minute's time may be estimated by millions and the wear is so rapid that I have seen the jet cut through a mill saw file in a few minutes time.

Gen. B. C. Tilghman and his brother R. A. Tilghman, when in company at a seaside watering place, somewhere near twenty years ago, observed an old bronze cannon, the touch-hole of which was enlarged and cut out by some action, quite common in such cases. Those

among us who can remember the old flint-lock guns can call to mind how common it was for the touch-holes to become "cut out" and require bushing. The cannon in question was an example of such cutting, and Messrs. Tilghman, after assuming a supposed number of times the gun had been fired, and aggregating the moments of time occupied in firing, or of tension, on the gun, saw that the flow of gases alone, during this inconsiderable period, could have no appreciable effect on the metal, and they straightway set about investigating analogous action in other cases.

Another and more direct example of the abrasive action of granular material impinging on hard surfaces, appeared in the depolishing of the glass in the cottages along the seashore where drift sand was carried in the air, serving in some cases to render the glass useless in so far as seeing through it.

Just at the time of writing this, Mr. F. T. Newbery, civil engineer, of this city, informed me that while engaged on the lines of the Southern Pacific Company through the deserts of Arizona and New Mexico, had to guard the lens in his instruments from the action of the sand in the air when working to windward, which, aside from Messrs. Tilghmans' observations, is the only notice of the matter I have met with.

After noting the circumstances referred to, Messrs. Tilghman returned to Philadelphia and at their laboratory began blowing jets of sand by means of a fan against glass, and by the results attained were induced to construct machinery for depolishing large panes or sheets of glass for commercial uses.

An early use of the sand blast was in cutting or figuring marble for decorative uses, first polishing the surfaces in the usual manner and then sinking with the

sand blast various figures or letters by means of stencils. One of the first applications of the sand blast, and a very important one, was in cutting the names on thousands of marble head stones for the National Soldiers' Cemetery at Arlington Heights, Virginia, opposite Washington. The contractor for these stones availed himself of the new process, and I have been informed, made a great deal of profit by this new and unexpected method of carving marble.

For cutting on marble, high pressure steam was employed; for ornamenting and depolishing glass, air currents were found best. These were produced by fans, and one impediment was, that the sand which was then carried through the fans soon cut holes in the casing or shells. After a time the machinery was modified so that nothing but the dust or fine sand in suspension passed through the fans, but at the present time air is not employed at all, the work being done by steam.

The objection to steam as a vehicle for the sand was the moisture and heat, but a simple discovery of Mr. Mathewson, the manager of the Tilghman Sand Blast Company at Sheffield, England, did away with both heat and moisture, and otherwise much simplified the working and cost of sand-blast plants. This simple invention consists in introducing a weak counter current of air to meet the steam and sand just before they reached the object acted upon. This stops the steam, but the greater weight of the sand permits that to go on and complete its work without appreciable retardation. The sand being hot and exposed to the counter current of cool air falls down dry as soon as it strikes the object being cut, and is immediately ready for use again. The evolution of this process or sand-blast required nearly one patent term of seventeen years, but this later

discovery has given the inventors a new term in which to gain some fair returns for their long labors and losses in developing the sand blast.

It is a strange matter that notwithstanding our boasted progress, the sand-blast, so far as I know, has made but little progress in this country. The company in Sheffield, before mentioned, use at least two hundred horse power of steam in their operations, and the application elsewhere in Europe is extensive, but in the United States, for some reason people have not availed themselves of it as they might have done for various purposes.

The main operations carried on at Sheffield is that of recutting files—not recutting old files, although some of that is done, too, but recutting new files, to improve them, and here comes in another important discovery in this process. At some place in New England, where a sand blast machine was employed, an attempt was made to clean a dirty file by holding it in the jet. The file was, of course, cleaned at once, but the effect was something more. The file, although a worn one, had all the characteristics of a new one, which, as all mechanics know, is a very noticeable change. Other files were treated in the same manner with a similar result, and the discoverer proceeded to patent the process in this country, assigning the invention to Messrs. Tilghman for European countries.

Then began another round of experiments to determine the precise nature of the effect produced. The experiments extended to giving a certain number of uniform strokes with files and weighing the metal cut away. New files and old ones were treated, until the precise nature of the effect was learned.

Every one knows how files are cut with chisels that

raise up shavings or teeth. These are of curved form and with a thin edge that soon crumbles or breaks, unless the cutting is skillfully done and the steel of good quality. When treated by the sand blast the files are held at an angle, so the sand impinges on the back of the teeth, cutting away the thin edge, but not affecting the face, so the teeth become strong cutters, without the thin curled edge left by the chisels in cutting. The operation is very rapid, requiring but a few seconds, and the value of the files is much increased, so much so, that a great many of the files made in Sheffield and on the Continent are treated in this manner. Sand, in the common sense, is not used in this process, but a mixture of sandy clay and water, thin enough to be circulated by pumps. This mixture of clay water, it may be called, is drawn in by induction nozzles and discharged through a thin slit made in chilled cast iron tips that wear away very rapidly.

It is a strange thing to stand in this factory—look about and see a process that had no existence twenty years ago.

I think it will be permissible after the description I have attempted the last two processes, to add a few more words respecting the inventors. After an acquaintance extending to several countries and covering a long period of years, I have never known any person so thoroughly acquainted with what we call technology, as Messrs. B. C. and R. A. Tilghman. They are much better known in Europe than in this country and not known anywhere except by their "works." Their contributions to the industrial arts has been extensive not only in the processes described, but in many others of less importance, or that are less known. They are also patient investigators in that field which our friends of the Acad-

emy here call "pure science;" tracing phenomena to their only useful end, which is their application to practical purposes.

In conclusion, I am compelled to admit that the subject of abrasive processes, although treated as compendiously as possible, is by no means complete in the two papers presented. Little or nothing has been said of exact processes, which form an important branch of the subject, and one I may have the pleasure of presenting before the Society at some future time.

TECHNICAL SOCIETY OF THE PACIFIC COAST.

INSTITUTED APRIL, 1884.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the statements and opinions advanced in any of its publications.

(VOLUME VIII. No. 1.)

THE NICARAGUA CANAL AND ITS RELATION TO THE FUTURE TRADE OF THE PACIFIC COAST.

An address delivered before the Society June 19, 1891, by Commander H. C. TAYLOR, U. S. Navy.

It may be supposed that your Society is especially interested in those technical questions which have a distinct bearing upon the Pacific Coast of the United States, and I may assume that the privilege you accord me to-night of addressing you on the subject of the Nicaragua Canal, is due to the fact that you recognize in that enterprise, when completed, an influence which will be felt upon the development of this western slope of the American continent.

I am sure you are correct in this belief, and that this enterprise will have consequences of large importance in the development of your industries and in your foreign commerce.

Thoughtful men have looked upon it for some years, amid the confusion of many suggested plans to recreate an American shipping, as the one certain and solid way out of the lamentable position our country now occupies upon the ocean. In a Nicaragua Canal our wisest statesmen have felt one well grounded hope for a new birth of the United States foreign commerce and car-

rying trade. With that noble waterway completed, we will have an American coastwise commerce of untold powers of expansion, carried on in the largest of sea-going ships and most stately of ocean steamships. Thus will be solved at once, without legislation, the great problem of American shipping.

In this the whole country is interested—the East, the West, the Gulf States—all see in it the salvation of our foreign trade and of the industries dependent thereon; but how much more should be the interest of the Pacific Coast in that enterprise, which will give to them in addition the control of the trade of the Pacific. San Francisco will be the terminus of the shipping lines from England, western Europe and our Atlantic Coast, and from here will go forth a continuous stream of cargo steamers, passing by way of the more northern ports and the Aleutian Islands to Hakodadi, Yokohama and those rich countries of Corea and the Amoor Valley, which await for their development nothing more than the outstretched hand of their maritime and commercial neighbor, the Pacific Coast of the United States.

The future of the Nicaragua Canal being thus so closely connected with the future of California, I shall not hesitate to describe before your distinguished Society some facts as to this canal, and some of the ideas which have clustered about the American Isthmus in the minds of thinking men for several centuries.

The intervening continent which blocked the path to the Indies for Columbus and his successors, was to them a serious disappointment—to them it was an obstacle. Centuries passed before the sailors and the merchants of the world became contented with the new geography—not, indeed, until the interrupting lands, peopled with

an active race, gave signs of becoming, themselves, a goal to be reached, of an importance equal to that of the Indies and far Cathay.

But again the old discontent grew, for the Pacific coasts of the ancient obstacle rose before the commercial eye, and their busy people throve and multiplied, and became buyers and sellers, shippers and receivers, and though the way had been long around Good Hope to the Indies, it was still longer around Cape Horn, to these western shores of America.

To-day, this discontent of commerce and shipping has so increased that we may truthfully say "through the old obstacle there must be cut a communicating way between the oceans, and this must be done now."

Hardly had Nunez de Balboa's first glance from the hills of the Isthmus rested upon the broad expanse of the Pacific, when the world immediately concluded that as so narrow a neck of land separated the two great oceans, throughout a length of nearly a thousand miles, nature must have provided somewhere in that extent a communicating waterway. For two centuries this problem was regarded as still unsolved. "The Secret of the Strait" occupied Christendom then as does the discovery of the North Pole now. Spaniards, Portuguese, French, Dutch and English sought diligently, from the Rio de la Plata, in South America, to the St. Lawrence River in North America, for this much desired channel. The search, as we know, was in vain, but before entire conviction came there were already projects being discussed for supplementing nature's defect by the work of man.

From the days of Columbus to the present time, almost all men of distinction whose attention has been drawn to the American Isthmus, have urged, at one point or another, an inter-Oceanic Canal. Cortez,

Saavedra, De Soto, among the earlier; Guizot, President Adams and Louis Napoleon, among the latter, are the more prominent names which occur to me now.

We pass by, with brief notice, earlier dreams and aspirations, and note that the Prince Louis Napoleon, while yet a prisoner in the Fortress of Ham, had given his approval to an enterprise which was to have been established under his name, and to be known as the Canal Napoleon de Nicaragua. Time will not permit my reciting to you his eloquent words, published in one of the reviews of that day, as to the great commercial and political importance of the strip of land which separates Lake Nicaragua from the Pacific Ocean.

It was shortly after the abandonment of the project by Napoleon, dazzled by the glitter of a possible crown, that the first organized attempt was made. In 1849 some American gentlemen formed a company known as the Atlantic and Pacific Ship Canal Co., and under concessions from Nicaragua, began actual work on a Canal.

The financial world was not ready for it—the enterprise was transformed into a transit company, which, after some years of carrying passengers and freight from one ocean to the other, by way of Lake Nicaragua and the River San Juan, presently faded away.

The interest in this line for a Canal continued, however, and was about to show some result when two other routes were proposed—that of a ship canal through the Isthmus of Panama, backed by the energy and former success of De Lesseps—and a ship railway across the Isthmus of Tehuantepec, in Mexico, promoted by an American Engineer, Captain Eades. So strong was the personality of these two men that the Nicaragua route was compelled to remain quiescent, until time and experience should balance these gentlemen's popularity and persuasive eloquence.

The death of Captain Eades, a few years ago, removed the Tehuantepec Ship Railway project as a competitor, nor has it since reappeared with any semblance of success.

This idea of carrying ships across the Isthmus upon a railway, was adopted after careful surveys had proved the impracticability at that point of a canal for sea-going ships. The idea itself was not new—records exist of Grecian triremes being dragged across the Corinthian Isthmus upon rough cradles, rolling or sliding upon a stone pathway specially prepared. Decided advantages were also gained in the wars between the States of Northern Italy, by transporting a squadron of vessels across a somewhat difficult country and launching them upon the Como and Maggiore system of Lakes. But Captain Eades proposed at Tehuantepec to take the largest ships with the heaviest cargoes and transport from sea to sea these immense burdens, supported by hydraulic cradles, traveling upon a three-tracked embankment. The shores which were to support the ship were portions of a hydraulic system, whose pistons rested upon a bed or mattress of water, and by this means all local inequalities of pressure or support upon the ship's hull would be eliminated. Large working models of the docks, cradles and railroad were exhibited in Europe and America. The details were, in many cases, original, and the infatuation of the present age for ingenious mechanisms has reached such a point that many people became thoroughly wedded to this project before even inquiring whether there might not be simpler methods which would not require this costly and complicated machinery.

As to a Panama Canal, time and experience have fully shown to the world the unfortunate mistake of M. de

Lesseps, in attempting a ship canal at the level of the sea, at Panama. Work has been for some time suspended upon the Panama Canal. The enterprise owes $420,000,000, and its assets will not, it is believed, amount to $20,000,000.

A great failure deserves notice next only to a great success, and the magnitude of this unparalleled financial disaster at Panama calls for some explanation and description.

In 1879 a small group of French gentlemen, who had obtained a concession from the Colombian Government to build a canal anywhere through its territories, but whose brief superficial examination of the Isthmus of Panama had given them practically no data on which to determine the best engineering route for a canal, persuaded M. de Lesseps, by means of which we will always be ignorant, to place himself at the head of their enterprise, to form a company, to purchase their concession from them, and to undertake the construction of a Panama Canal (at the level of the sea). M. de Lesseps thereupon caused to be called together, in Paris, representatives of the maritime countries of the world, to attend an International Canal Congress to decide upon the location of the Canal, and upon the general features of its construction.

This Congress, after some deliberation, decided by a large majority upon the Panama route, as proposed by de Lesseps. The Congress was warned, on the part of England, by the eminent engineer Sir John Hawkshawe, and on the part of the United States by Admiral Ammen, that such a canal was impracticable—that it could not be constructed, and, if constructed, could not be conserved for the use of shipping. The hilly country, the raging course of the Chagres River, the torrential

rains and the pestilential climate forbade the hope of success. To these remonstrances de Lesseps, flushed with the success of Suez, and impatient of contradiction, would give no heed, and the French people—loyal to him, and proud of his well-deserved reputation—swarmed about his offices and liberally subscribed to this new project of the great promotor.

The results are known to you. The newspapers of the day, everywhere except in France, have kept careful record of the various steps in this unfortunate enterprise.

Until 1887, de Lesseps clung to the idea of a sea-level canal. This was, indeed, almost a necessity, for he had often given public utterance to his opinion that Nicaragua was by far the best point for a canal with locks, but that *he* proposed to build a sea-level canal. In that year, however, after enormous expenditures of men and money, he was compelled to change his plans to a lock canal at Panama. Though the situation was very unfavorable for a lock canal there, it was not absolutely impracticable as was a sea-level canal, and might have been constructed had he changed his plan earlier, before so much money had been spent.

It was, however, too late; and after raising, at ruinous discount, some further sums, he was obliged to discontinue the work for lack of funds. There seems to be no hope of a revival of this project in the minds of those best informed in the commercial world. Lately, news has been received that the concession has been renewed and more time given to the Canal Company to complete the work; but Colombia has not granted this without exacting heavy compensation, and the company has, besides, the task before it of raising money upon an enterprise practically dead. We need not dwell upon the

sad picture of this heroic old gentleman sinking under the burden of so terrible a reverse. De Lesseps has done great service to France and the world, and has made only one mistake—but this, a gigantic one.

Let me ask your attention, now, to what seems to promise happier results—the Nicaragua Canal.

The great mountain system of North and South America, stretching from the Arctic Ocean to Cape Horn, sinks to its lowest point in the Republic of Nicaragua, producing thus a comparative depression unique in character. This depression or basin is occupied by the waters of Lake Nicaragua, a fresh water, inland sea, 100 miles in length by 50 in breadth, and with general depths varying from 50 to 100 feet. The western shore of this lake is only 13 miles from the surf of the Pacific Ocean, and the intervening neck of land, on the route selected for the Canal, has a maximum elevation of only 40 feet above the lake. The elevation of the lake is 110 feet above the ocean, and the dividing ridge 150 feet above the ocean.

Although this great sheet of water is so close to the Pacific side, its waters drain to the eastward, by way of the River San Juan, into the Caribbean Sea, a distance of about 120 miles. The river is navigable, to some extent; a steamer drawing six feet of water has ascended from the ocean to the lake, in the last few years, although being delayed somewhat in getting up the rapids.

These facts will indicate to you how much nature has already done toward a Canal, by this route, and a closer investigation develops many other features most favorable, in an engineering point of view. This lake, being a great reservoir, is but little influenced by the rainfall, and the same is, of course, true of the upper portion of the river which is its outlet.

The main features of the Canal now being constructed are the following: The lake and upper river will be the summit level of the Canal; there will be a cut through the neck of land between the lake and the Pacific, the greatest depth of this excavation being 40 feet to the water surface, and the Canal quickly emerging upon the western slope of this neck of land, will reach the Pacific through the valley of a small stream which flows into that ocean, descending to the sea level by means of three locks.

Going eastward from the lake toward the Caribbean Sea, the San Juan river will be followed for a distance of 64 miles from the lake, at which point the river will be dammed to such a height as will back its waters to the lake, raising the level of the lake to a uniform height of 110 feet above the level of the sea, and thus deepening the water in the upper river to such a degree that but little dredging will be needed throughout the 64 miles.

The upper river, being of the same general character as the lake, is not subject to violent freshets. The lower portion, receiving some large tributaries from the neighboring mountains, possesses a different and more unstable character. For this reason the line of the Canal leaves the river at this dam 64 miles from the lake, and pursues a straight course across country to the Caribbean Sea at Greytown, making use of some convenient interior valleys by means of dams at their outlets, and thus continuing the summit level until it emerges from a confining range of hills, and looks down upon the 18 miles of flat and marshy land, between the hills and the coast. Here, upon the eastern slope of these hills, the Canal descends by three locks, to the level of sea, and continues its course by dredging to the harbor

of Greytown. The total distance from ocean to ocean, by this route, is 169 miles, of which 27 miles will be excavated Canal, and 142 miles free navigation in Lake Nicaragua, the river San Juan and basins in the valley of the smaller streams.

To describe it more in detail, beginning at the Atlantic or Caribbean side, the Canal starts from Greytown Harbor by dredging nine miles to Lock No. 1, in the valley of a small stream, the Deseado. Lock No. 1 has a lift of thirty feet. The dimensions of all the Locks are uniform, namely, 650 feet long by 70 feet wide and 30 feet deep.

From lock No. 1 to lock No. 2, 1¼ miles, the Canal occupies this valley, which is flooded by the construction of embankments, and thus reduces the amount of dredging to be done. Lock No. 2 has a lift of 31 feet. Lock No. 2 to Lock No. 3, two miles, continues in the valley of the Deseado, which is flooded by dams and embankments, but slight excavation being necessary. Lock No. 3 has a lift of 45 feet. This brings us to the summit level of the Canal. For 2½ miles beyond this Lock, the same system of embankments avoids the necessity of any excavation, the flooding of the valley producing depths of from 30 to 70 feet. The Canal then enters a rock cutting in the eastern divide, 3 miles long, and of an average depth throughout these 3 miles of 110 feet. This cutting contains 21 per cent. of the total excavation needed for the whole Canal. Emerging from this cut the Canal line enters the basin of the Cañon (valley) San Francisco. Dams and embankments are used to impound the water of this stream, and to form a long and narrow lake, whose length is in the direction of the Canal line.

Passing thus through the San Francisco and adjacent

valleys, the Canal enters the River San Juan just above the dam in that river, at a distance of 12½ miles from the eastern divide cut. The Canal line then proceeds from the dam in the River San Juan, up to the Lake, a distance of 64½ miles, then across the Lake Nicaragua, a distance of 56½ miles. From the Lake to the Pacific, the distance by the Canal is 17 miles, of which 11½ miles is in excavation, and 5½ through a basin in the valley of the small streams Rio Grande and Rio Tola.

The dimensions of the Canal now under construction are such as to accommodate not less than 11,000 vessels with a net tonnage of 20,000,000 tons a year. Its width throughout most of its length is 120 feet at bottom, 210 feet at the top, but in the eastern divide, the prism is reduced in area, the width being 80 feet at top and bottom. This contraction in width extends for 3 miles. The same dimensions occur in the western divide cut, between the Lake and the Pacific, for a distance of 5 miles.

The estimated time of transit is as follows, by steamer:

	H.M.
26.030 miles of Canal, at five miles an hour.....	5.12
21.619 miles in the basins, at seven miles an hour.	3.05
64.540 miles in River San Juan, at eight miles an hour.....	8.04
56.500 miles in Lake Nicaragua, at ten miles an hour	5.39
6 lockages, at 45 minutes each.....	4.30
Allow for detentions in narrow cuts.....	1.30
Total time of transit.....	28.00

Allowing 45 minutes for a vessel to pass a lock, the number per day will be 32, or in one year 11,680—or an average tonnage of 2,000 tons, will give 23,360,000 tons per year.

The water power at hand, ready for use throughout

the length of the Canal, makes its illumination by electricity quite inexpensive, and this estimate of the capacity of the Canal is, therefore, calculated for work through day and night.

The water supply is abundant—the Lake alone, without any of the streams flowing into the river, provides a daily supply of 1,000,000,000 cubic feet in excess of the needs of the locks. Leakage and evaporation have been considered in this calculation.

Of the two terminal harbors, Greytown on the Atlantic side has been, in its time, an excellent harbor, but its mouth has been closed by a sand bar, caused by the sand in the vicinity drifting across the entrance. A pier or jetty has been built lately, into the sea, at right angles to the shore on the windward side of the old entrance to prevent this drifting of the sand, and has already caused the harbor to open, permitting the Company's dredges to pass in and out; and the entrance thus sheltered is becoming deeper every day. Dredging is being carried on to assist the forces of nature. Brito, the point on the Pacific Coast, where the entrance to the Canal is to be, has no harbor, and the deep water on that coast prevents long break-waters. But Brito is situated at the mouth of a broad, alluvial valley which can be dredged from the beach inland to any distance required for the needs of a terminal harbor. These needs, as will be observed at Port Said in the Suez Canal, are not extensive as far as area goes.

The calculations which have been made as to the traffic using this Canal, when constructed, have not been permitted to include any of the larger prospective increase, which may be counted upon with reasonable certainty, as a result of the existence of this waterway. It has been thought better to estimate only for that

traffic which will be already existing and ready to use such a Canal as soon as it shall be open. Leaving out, then, the extraordinary estimates made for the Panama Canal traffic, and considering only the actual statistics, we find the vessels ready to use the Canal now amounting to about 6,000,000 of tons, and at the present rate of increase there would be in 1897 about 8,000,000 of tons annually.

Putting the tolls at two dollars per ton, we should have receipts of $16,000,000 or, allowing liberally for operating expenses, a net revenue of $15,000,000, or five per cent. upon $300,000,000.

The cost of the construction of this great work has been carefully estimated, and liberal allowances made for all possible contingencies. The figures of these estimates are not essential in this description, but I may say that the result is quite satisfactory to those engaged in the work.

Let us consider now the effect of a finished Nicaragua Canal upon the commerce of the Pacific and the World. And first let us say that this Canal will join two worlds of commerce; the one being composed of those countries and peoples which front upon the Atlantic, and upon its tributary seas, gulfs and rivers; the other, those nations whose coasts form the shores of the Pacific.

Of Suez it may be said that its principal office is to connect two sections of a trade world, not two distinct, ever sundered, commercial world spaces. Those sections were not strangers in trade to each other before Suez was opened; since the dawn of history slow lengths of innumerable caravans toiling through sandy deserts have incessantly deployed upon the shores of the Eastern Mediterranean bringing the rare and costly products of Persia and India to the ships of Phœnicia, of

Greece, of Rome and later to those of Venice, Genoa, Spain and England. The Suez Canal did not create a new trade—it improved and increased a trade already existing between sections, and only between sections. I will not be suspected in saying this of trying to belittle that great and noble work, whose usefulness to mankind cannot be over estimated.

The Nicaragua Canal, on the contrary, will connect two areas of commerce hitherto without connection and quite independent of each other—each with its own trade channels and currents circling and eddying in response to the various and changing demands of merchandise and the needs of its transportation. It is true that the Atlantic system reaches in some degree to Australia, China and Japan, and that fish and lumber, and some Chilean and Peruvian products pass in limited quantities around Cape Horn to New York and Europe; but the intervening distances are too great to produce anything like a union or joining of the trade systems of the Atlantic and Pacific.

They are distinct and separate, and will so remain unless joined by a waterway through the American Isthmus. This done we should with reason expect a gradual mingling of the elements and factors of transportation, and, as the new necessities were felt and the new conveniences realized, there would gradually be effected changes of great importance to the commerce of the world—far more so than the changes which Suez effected as between the Atlantic and Indian Oceans. More remarkable still, however, in my belief, will be the great increase of trade; the creation of new productiveness in many fields hitherto unworked resulting from the completion of the Canal and the consequent open-

ing of convenient markets and active demands for various commodities produced.

Nothing in history seems to have been more regular than the movement from east to west of the trade centers of the world. Our earliest glimpses of ancient times show a busy interchanges of commodities about Northern India, Persia and the adjacent seas. Later, these activities transferred themselves to Phœnicia, Egypt and the other countries of the Eastern Levant. Again Rome and Carthage, still more to the west, struggled for commercial ascendency in the Mediterranean. Still later—though after long interruptions—Venice and Genoa yielded to Spain and Portugal the hold of the seas, and these, very quickly, to northwestern Europe and finally to England. There, in England, has remained for several centuries the central power of sea trading—a notable and worthy resultant of the great maritime qualities which she holds and America holds as a heritage from the ancient nations of the north.

Judging of the future in the light of the past, and observing the rapid growth of an energetic and industrious race on the other side of the Atlantic, we should naturally look to see, in time to come, some continuation of this westerly transference of the world's trade centers. If I am correct, and such be the tendency, the opening of a Nicaragua Canal would have a marked influence upon such a movement.

Where this influence would center, we cannot tell—around what particular point would group themselves these future commercial forces, it is impossible to say. It may be that the prophecy of the Prince Louis Napoleon will be verified and a great metropolis grow up at the Canal itself, having the importance in our modern world that Constantinople, from its similarly admirable possession, possessed in ancient times.

However this may be, the Canal possesses a great interest in its bearing upon this tendency of the world's commercial center to shift gradually from east to west. It is not only that the Canal will aid commerce—that it will connect two oceans—but that a large proportion of the world's merchandise that has hitherto, in all ages gone from east to west, will now go from west to east. Not only will the circulation of such traffic be quickened and its volume increased, but its direction will be reversed through all the veins and arteries of trade.

The time at my disposal permits me only to touch upon many points which deserve thorough discussion, but I shall be well satisfied if this slight consideration of the subject should draw the attention of some of the able minds of this distinguished Society to the approaching change in commercial conditions due to a Nicaragua Canal.

Five years must elapse before the Canal is open, but that period can be well devoted to a thorough study of the future commercial situation and to such preparation as will enable California and the other Pacific States to avail themselves of the advantages to be then provided.

Permit me to indicate very briefly a few of these advantages, and first let me ask you to rid your minds of any lingering error as to the shortest routes across the North Pacific Ocean.

If there be any among us who believe that the shortest distance between the Mexican Coast and the Chinese Coast is on an east and west line, passing through or near the Sandwich Islands, let them disabuse their minds of this belief, for it is a fallacy. A very popular fallacy but one very obstructive to a correct judgment of these questions. The shortest distance between those

coasts, the Chinese and the Mexican, is on a great circle of the earth, and such a great circle passes from Hong-kong and Amoy, northward through Japan, close to the Aleutian Islands, 1200 miles north of the Sandwich Islands, within a day's run of San Francisco, and will touch the Southern part of Lower California.

This great circle route is several hundred miles shorter than that route which follows the east and west line and passes through the Sandwich Islands.

I wish to emphasize this fact, for much depends upon it—much of vital interest to the future of San Francisco, Portland and Los Angeles, in fact to the whole Pacific Coast line of the United States.

I do not doubt that to the well-trained intellects of this Society, these truths have long been apparent, but it would be well that they should impress upon others outside of their membership the exact facts of the case; for statements have been lately made—nay, published and widely circulated—that the shortest route from China and Japan to Nicaragua lies far to the south, and that if a Nicaragua Canal were opened, shipping would cross the Pacific within the tropics, and San Francisco be left shippingless, tradeless, and with the grass growing in her streets. It is when ignorance such as this stalks abroad, that the great benefit of a Technical Society to the community becomes apparent. It is when ignorance perverts the truth (unintentionally doubtless, but nevertheless injuriously) and in so doing endangers the future of a great city, and retards its development, that the real usefulness of a group of able and scientific minds is most appreciated by their towns-men, and by all the business interests involved.

It is interesting to notice that in following the great circle route from Japan, a ship may enter San Francisco

and then continue her voyage down the coast of America to Nicaragua, and will then have traversed a total distance several hundred miles less than the route by way of the Sandwich Islands.

The distance *via* Honolulu, which appears on the ordinary maps and charts to be much the shorter, is in reality several hundred miles longer.

I need not dwell upon the cause of this apparent discrepancy.

Mercator's method of projection, though convenient in many ways, has, as the Society knows, the fault of distorting the higher latitudes, thus producing such errors as I have mentioned. To compare intelligently the distances covered by different routes, a projection is needed which will exhibit the great circles of the earth as straight lines. Such is the Gnomonic Projection, of which I have here a chart, and whose principles are doubtless known to you all. I have referred to this projection because of its close connection with the study of Trans-Pacific routes.

There are other reasons why the northern route along the Pacific Coast must be chosen. The freight trade of the future will be largely carried in cargo steamers, and for such steamers a necessary condition of success and profit is, that they shall not have too much of their cargo space occupied by their coal supply. In other words, they must carry little coal, and hence take coal oftener. For this reason, numerous coaling stations on their trade routes are an imperative necessity.

Now, upon or near the great circle route convenient coal ports exist or can be created without difficulty or undue expense; indeed one only need be created, the rest already exist. That one would be in the Aleutian Islands at a point which would divide into 2,000 mile

trips the 4,000 miles between Japan and San Francisco. Near the Aleutian Islands has been lately discovered one of the great fishing regions of the world, and there is little reason to doubt that ships carrying coal to that locality would soon find return cargoes of the dried and salt fish, which is an industry soon to be developed there.

Vessels would, therefore, coal at Hakodadi, then at one of the Aleutian Islands, next at San Francisco, Acapulco, and so to the Canal.

We should also note here that on a great trade route the stopping places for coal should also be ports possessing some trade, in order that an interchange of products along the whole line may ensure still greater profits to the carrier. This is notably the case in the trade between Asia and Europe via the Suez Canal. Steamers sail from Japan for England with less than a third of their stowage space occupied by cargo, fill up at Shanghai, discharge some and take aboard some at Hongkong, gather some business perhaps at Singapore, Penang and Ceylon; and thus make the way trade an important auxiliary to the through freights.

In considering the southern route across the Pacific, through or near to the Sandwich Islands, we are confronted by the fact that no coaling stations exist west of that group, and that none can be established without great expense. The nearest practicable islands, namely, the Marshall Group and the Eastern Carolines, are far to the south of the southern route, and they are quite unproductive, and could not give any return cargoes to ships bringing coal there, thus raising the price of coal freights to the islands to an unduly high sum. Some sailing ships will, of course, use the southern route when westward bound, as the favoring northeast trade winds will compensate them for the greater distance to

sail; but I do not anticipate that any cargo steamers will use this route, nor any eastward bound sailing craft.

I have purposely left out of consideration in discussing Trans-Pacific routes, the swift steamers of the mail and passenger service. Nor will I now confuse the issues before us by bringing them to your attention.

They will increase, though more slowly, as the freight trade grows, but it is that freight trade and the conditions under which cargo steamers will find themselves, which should engross our most serious attention, as being the more solid and important factors of a nation's commerce.

What then do we see in the future, resulting from the existence of a Nicaragua Canal?

A continuous stream of ocean steamers leaving San Francisco to touch at the Aleutian Islands, to carry our flour and other products to Hakodadi, Yokohama, Kobe, Shanghai and Hongkong; tapping at convenient points the products of Corea and the rich valley of the Amoor.

Another continuous line, leaving San Francisco for Mexico and the canal, New Orleans, New York and Europe, while subsidiary lines from other coast ports connect at San Francisco with the great trade current, sweeping along our Pacific Coast from the Canal to Asia and return.

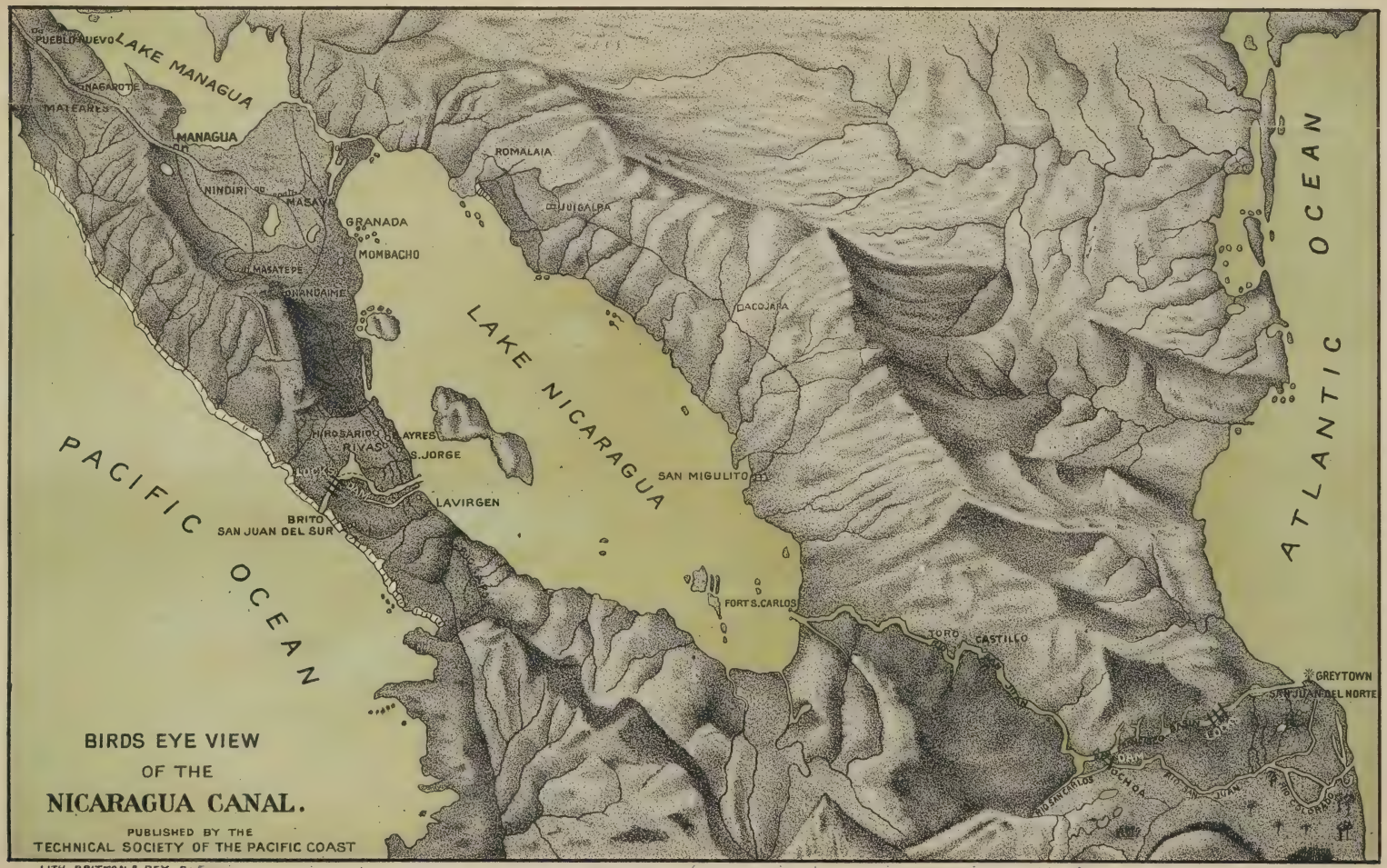
We see this Canal, which has been opened at a cost of $75,000,000, paying in the first year of its use 5 per cent. interest on $300,000,000, and under a wise and liberal management, tolls being steadily reduced, until this great waterway is only a little less free than the open ocean.

We see on Lake Nicaragua swarms of shipping and on its shores busy towns springing up in that lovely and

salubrious climate; while on the coasts from which come this commerce, we see a renewed impetus communicated to the industries of the States and increased power and glory to the nation.

This is no dream, my friends. These are hard and practical facts which we have considered to-night. The men who conduct the affairs of the Canal are practical men. There are no dreamers among them.

Least of all is that distinguished statesman a dreamer, who has honored the enterprise by accepting the leadership of it, and who is here to-night to assure you of his firm and enduring confidence in this, the greatest of all undertakings since Columbus discovered the Continent of America.



BIRDS EYE VIEW
OF THE
NICARAGUA CANAL.

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(VOLUME VIII.—No. 1.)

PHYSICAL AND GEOLOGICAL TRACES OF PERMANENT CYCLONE BELTS.

BY MARSDEN MANSON, C. E., MEM. TECH. SOC. P. C.

The circulation of the atmosphere, in obedience to existing laws, antedates the dawn of geological time, therefore the effects of the formation and movement of areas of low barometric pressure, or cyclones, must be looked for in all subsequent time. These effects become traceable when, by reason of certain physical conditions, particular portions of the globe are more severely and frequently subjected to cyclonic action than others.

ORIGIN OF CYCLONES.

Cyclonic activity is developed in those regions of the globe where the air over any given area is warmer than the surrounding air. This condition creates upward currents, lessening the pressure of the atmosphere, and is recognized by low barometric readings.

The surrounding air flowing in towards the cyclonic area receives a rotary motion from right to left,* and has an apparent motion from west to east, in consequence of the rotation of the earth.

A cyclone, once generated, has its energy increased

*In the Northern Hemisphere.

by the latent heat set free in the condensation of the moisture of the warm currents drawn in towards its vortex from at least one quadrant. In its motion eastward this energy is further intensified by the increased precipitation caused by the chilling effect of continental elevation.

Under favorable conditions a cyclone will traverse half the earth, and indeed there is no reason why cyclones should not successively continue to circle the globe, subject to the deviations caused by the particular meteorological conditions existing in the quadrant northeast, east, and southeast of their positions.

The areas most favorable to the development of cyclones are that portion of the North Atlantic warmed by the Gulf Stream, and the corresponding area of the North Pacific covered by the Japan current. These two vast "ocean rivers," the Gulf Stream and the Japan current, moving on arcs nearly parallel and on opposite sides of the globe, transport an immense amount of tropical heat into the temperate and polar regions, much of which is spent in heating the air in contact with the surface.

CYCLONES GENERATED UPON LAND.

Areas of low barometer originating upon continental areas exposed to great summer or tropical heat, generate a class of storms classified by Maury as monsoons. Their general character is similar to that of cyclones, but the interferences to true cyclonic motion are great. They could not have been established until *after* the upheaval of the continents. Their areas are much smaller, and their action is confined to the continents upon which they originate, unless, by being drawn into the older and more influential ocean cyclone, they intensify its power. They occupy the basins of the great river sys-

tems of the tropical and temperate regions. Their production in winter over the northern hemisphere is replaced by the opposite condition, that is, an area of high barometer, or anti-cyclone. These anti-cyclones are the most potent factors in checking a mild, or forcing aside a violent cyclone traversing the continents of America and Asia.

The distinguishing physical and geological characteristics of the areas subject to monsoons are:

(a) Maximum differences in elevations between mountains and valleys.

(b) Recent geological formations.

(c) Absence of evidences of glacial action, except in their most elevated, or northern limits.

Although interesting in their action and results, it is not necessary to the purposes of this paper to further notice cyclones of this class.

COURSE OF OCEAN CYCLONES.

In its easterly course a cyclone may be checked, or forced out of its ordinary line by the existence of an anti-cyclone, and its path may be accurately predicted if the barometric pressures and general meteorological conditions in the quadrant to the northeast, east, and southeast of its position are known. The locus of constant maximum cyclonic activity in the northern hemisphere is about latitude 50°. During winter it is south, and in summer north of that line. The conditions favorable to the formation of cyclones are greatest in winter, hence the greater frequency and increased precipitation of winter storms. The breadth of the area of lowest barometer varies from several hundred to a thousand or more miles, and the effect of such low barometer in producing precipitation is several times this width. Within its influence minor local disturbances of terrific energy, such

as tornadoes, hail and thunder storms, are developed. These are fully explained in the able reports and publications of Lt. Finley.

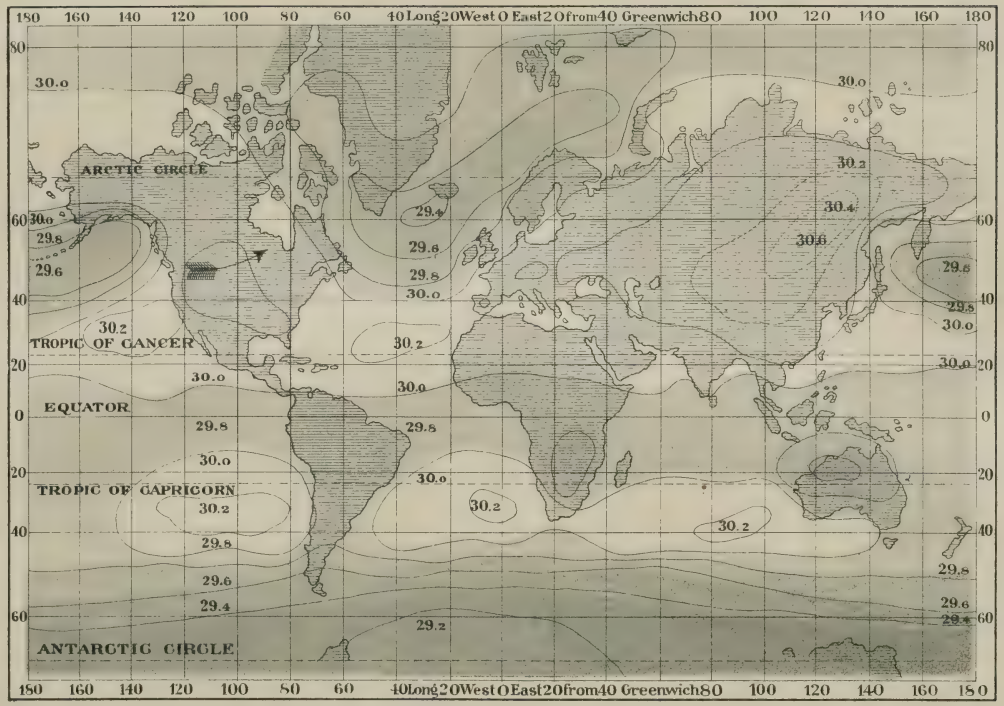
The annual northerly and southerly oscillations of cyclonic belts are peculiarly noticeable in the region just south of their general course from the Pacific, across the continent of North America. In winter, these cyclones strike about latitude 47° and their effect in influencing precipitation frequently reaches to latitude 33°. In summer, the causes producing them decrease and retreat northward beyond definite observations, and their southern limit of influence is rarely felt south of latitude 41° or 42°. Hence the wet and dry seasons of California.

The accompanying charts, showing the areas of average barometric pressures for January and July, are from the recent edition of Warren's Physical Geography by Prof. Brewer, of Yale.

The observations in the northern hemisphere from which these isobars are drawn, are extended and definite and the deductions therefrom are reliable. This is not the case south of latitude 30° S.

It will be observed that a cyclone, originating in the North Pacific, would find its course eastward across the continent of North America along the line of least resistance and be drawn into a corresponding area in the North Atlantic, thence across Europe in the same latitude. It is probable that in an earlier period of the earth's history, the conditions for a further passage eastward were slightly more favorable than those now existing across the great Asian continent, and that the northeasterly course is a more recent one. Complete data for a full consideration of this problem are not at hand.

There is no reason to assume that conditions mate-

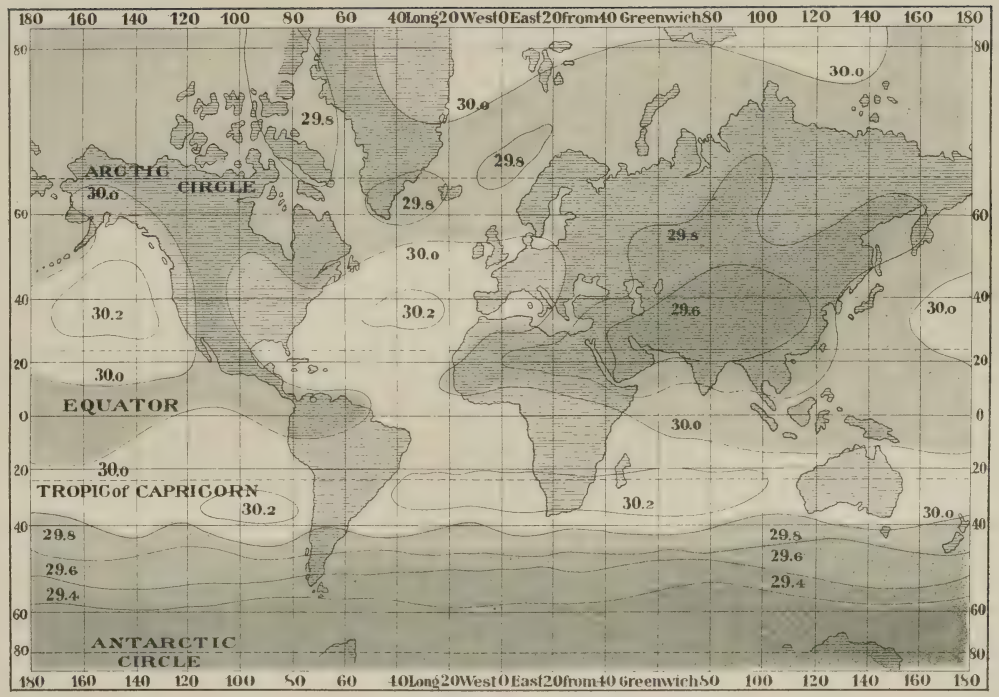


ISOBARS FOR JANUARY.

The shaded portions between the curves indicate the areas of a barometric pressure of less than 30 inches.

[After BREWER]

Technical Society of the



ISOBARS FOR JULY.

The shaded portions between the curves indicate the areas of a barometric pressure of less than 30 inches.

[After BREWER]

rially different from those now existing, controlled the movement of cyclones since the Archaean period; and there are facts tending to show that the lines of cyclonic movement around the globe, between latitudes 50° and 60° N., have practically remained unchanged since the upheaval of the continents along that line, and that this continued lessening of atmospheric pressure may have played an important part in their upheaval.

In the same manner, the escape of vast volumes of hot gases and lava, during volcanic action, heated and expanded the atmosphere, thus relieving its pressure, and thus aiding in the upheaval of the adjacent crust.

In order to fully appreciate the effect which a difference of barometric pressure is capable of producing, one must realize that over each square foot of area subjected to one inch less pressure than another, a relief of 70.5 pounds obtains. Upon a square mile this amounts to over 877,000 tons. A difference of one inch or even more is not unusual; indeed, an inch is not far from an average, and acts over areas several hundreds of miles in width. This action is repeated every few days now, and could not have been inoperative at any period within the range of geological research, since its causes have their origin in the older sphere of Cosmology.

This force may seem insignificant to the geologist accustomed to consider forces of vaster magnitude, but the factor time, being great, brings the results entirely within reason. The geologist, in dealing with sub-aerial denudation, and the vast sedimentations resulting therefrom, accounts for the aggregate effects of a much milder force —because of the immensity of the time during which the force has been acting.

It is impossible for this cyclonic force to have been thus active for ages, along certain reasonably well de-

fined lines, without producing a very marked effect, and particularly if the surface acted upon was plastic or semi-plastic and in a state of equilibrium, or at a later period too rigid to yield otherwise than by being worn away.

The direct effect of this lessening of pressure would be equivalent to a lifting force, and hence along the lines of its action the greatest upheavals would occur. The results of other cosmic forces would be accelerated or retarded, according to the direction of their lines of action.

Continental areas in process of upheaval would—

1st. So interfere with the circulation of the ocean currents, as to concentrate the flow of warm equatorial waters upon certain areas;

2d. They would reach their maximum height along the lines of maximum cyclonic activity. Hence, along those lines, would at once be established the summit or division of waters flowing north and south. This would notably be the case in great plateaus, where the forces of upheaval have been more uniform, and the rupture of strata less frequent. In addition to this, along these lines would be established the theater of the most active denudation, which would result in the maximum exposure of the oldest strata along this belt of cyclonic movement; whether the denudation be sub-aerial, as during the warm Paleozoic era, or glacial as later when the crust of the earth had cooled and thickened.

The general proposition would also be true, that later geological formations would occur in the order of their ages north and south of this belt. As a second consequence of this concentration of denuding agencies, the differences between mountain and peak elevations, and valley and plateau elevations, would be reduced to a

minimum; for although both would reach their greatest height along these lines, upon the mountains would be concentrated the greatest action. Mountains both north and south would remain higher, and as the plateaus in their latitudes had been less upheaved, and the valleys less filled up, the comparative elevations would be greater; or in regions north and south of cyclonic belts, differences in land elevations would reach their maximum.

The evidence is complete* to demonstrate that the maximum glaciation was along these belts, instead of being from the pole southward, as affirmed by Dr. Croll.†

Dawson and others have observed that at, and near the mouth of the Mackenzie River, and over the whole of the northerly part of British America, the glacier movement was north. There is no controversy regarding the direction of such movement, south of the lines of cyclonic movement across the continents. It is more natural to assume that glacial dispersion should occur along lines of maximum precipitation rather than from the pole, on account of its being the locus of maximum cold; the hypothetical piling up of glacial ice at the pole to such a thickness as naturally to flow south is thus avoided, and the laws of gravity not so seriously taxed.

The accompanying chart of glacial movement is from various sources.

Glacial movement northward would be retarded, or even entirely checked, during a period of increasing glaciation by the non-disappearance of ice, and its movement southward would be accelerated. Maximum glaciation along the lines of maximum precipitation in no way interferes with the various theories regarding the cause of the glacial period, and is borne out by the

*The Ice Age in North America, Wright.

†Climate and Time; Climate and Cosmology.

observations of Dawson and others; also by the fact that the southern traces of glacial action on the continent of North America, are where the maximum precipitation now has its most southerly extensions; namely, on the southwesterly end of the Sierra Nevada, in latitude 36° and in the center of the great depression, extending up from the Gulf of Mexico in latitude 38°.

In the former locality, the increased precipitation is caused by the chilling effect of the high mountains on the warm southerly and westerly winds; and the latter point is exactly where the warm, moist air drawn up from the Gulf of Mexico by cyclonic action, encounters the cold of the great plateau extending through the continent.

At these two localities, increased precipitation is natural, and easily accounted for, and exactly in them we find that glacial action extends as far south as latitude 36° N. in the Sierra Nevada, and 38 N. in the valley of the Mississippi-Missouri.

No portions of the globe show more extensive evidences of glacial action than those portions in the immediate path of cyclones around the northern hemisphere, and these evidences reach their maximum where the cyclone first encounters the continent and where the precipitation reaches its maximum, or in Washington and British Columbia, and in the corresponding latitudes in Europe and Asia.

SUBMARINE EFFECTS OF CYCLONIC ACTION.

The submarine effects of cyclonic action are traceable by shallow seas. The same causes which aided in making the continents broadest and highest between latitudes 50° and 60° north, made the Atlantic and Pacific

oceans shallowest in the same latitudes. The telegraphic plateau revealed by Brooke's deep sea-sounding apparatus, is probably not altogether attributable to the deposits swept northward by the gulf stream, nor to the detritus from melting icebergs as affirmed by Maury.

By the same general agencies and in the same manner as now, the heat of the tropics has been for ages transported to the Arctic, rather than to the Antarctic regions. The resulting cyclonic action has been influential in producing the broader land exposures and shallower seas of the northern hemisphere. The Atlantic telegraphic plateau has its corresponding plateau in the Pacific, and both are counterparts of the great continental plateaus between parallels 50° and 60° N.

The continent of North America serves as an illustration of the peculiar traces of cyclonic movement, for—

1st. Both physical conditions and meteorological research agree as to to the natural course of cyclones about latitude 50°.

2d. Along this parallel rise the great river systems of the continent, one flowing south into the Gulf of Mexico, and the other north, into the Arctic Ocean.

3d. In this same belt the Rocky Mountains and the Selkirks are crossed from the summit of the plateau at elevations of 5,300 and 4,300 feet respectively, whilst at no other point of their course can they be crossed at such low elevations.

Again, the peaks in this belt are not so high by from one-half to a full mile as Mount St. Elias ($62\frac{1}{4}$° N.), Mt. Wrangel (64° N.), or as Mt. Ranier (47° N.), Mt. Shasta ($41\frac{1}{2}$°) and Mt. Whitney ($36\frac{1}{2}$° N), all of which are still subjected to glacial action.

The valley and plateau elevations in the latitudes cor-

responding to these peaks are lower than in the cyclonic belt; almost within sight of Mt. Whitney, the most remote from this belt, are depressions below the level of the sea.

4th. Along this same cyclonic belt the greatest exposures of Archaean rocks occur, with their maximum southerly exposure in the center of the continent, where the cyclone traversing the continent was reinforced in the work of denudation by the precipitation from the warm, moist air drawn up from the Gulf of Mexico.

So far as geological research has revealed them, the later formations occur in the order of their ages as the work of the cyclone has upheaved and uncovered them.

The conclusions are evident:

The continued movement of cyclones along the lines indicated, has resulted in two effects—

1st. The upheaval of the crust to its maximum along these lines.

2d. The increased precipitation has subjected these summits to the maximum denudation, thus exposing the oldest rocks on the surface of the globe.

DISCUSSION.

Professor Joseph LeConte:

1. Mr. Manson's paper assumes the ordinary view as to the cause of cyclones. This has recently been called in question by some of the ablest meteorologists. I think, however, he is quite right. Let the meteorologists settle it among themselves. In the mean time, those who are not experts must assume what represents the present condition of science.

2. A cyclone belt about 50°–60° latitude seems a

probable fact of observation. If so, I would represent the cause in this wise: It is certain that the return current from the equator deflects to the right and becomes about that latitude an eastward current. Thus there is certainly a great circumpolar whirl — a geo-cyclone — with its center at the pole and its circumference about 50°. Now, as about the margin of ordinary cyclones are formed smaller but more furious whirls, viz: tornados, so about the margin of this geo-cyclone are formed smaller but swifter whirls, viz: the ordinary cylones.

In the case of ordinary cyclones, the subordinate whirls (tornados) are mostly in the southeastern quadrant. This is probably connected with the movement of translation. In the geo-cyclone, being stationary, the subordinate whirls (cyclones) may occur anywhere. This is determined by local causes, such as warm oceanic currents, etc. If this view be right, then there was always a cyclone belt throughout all geological times, and even in pre-continental times, as indeed Mr. Manson assumes.

3. It is true, also, that in North America and in Europe (area more doubtful), the geologically *oldest land, the nucleus of the present continents*, was about this latitude, and that the continents, especially North America, developed by gradual upheaval and additions of newer strata north and south of this nucleus. This oldest land, along the cyclonic belt, would be the most eroded, for two reasons: 1st, because it is the oldest and therefore longest subjected to erosure; and 2d, because this is the region of greatest precipitation of rain and snow, and of severest glaciation, as Mr. Manson has shown.

4. But that low barometer of cyclone belt was the *original cause* of upheaval in that region, and therefore localization of the continental nuclei is, I think, untena-

ble—not because the cause is too small, but because it is not cumulative.

Suppose the earth's surface in a state of perfect iso-static equilibrium, a fall of barometer of one inch would cause a rise of the crust about five inches (specific gravity of crust 2.6). If the barometer remained low, the iso-static equilibrium would be simply restored at that level permanently, except in so far as it may be destroyed by erosion. This, it seems to me, is the fundamental fallacy so far as regarding low barometer as a direct cause of continental upheaval. But indirectly it is an important cause; for the belt of low barometer is the belt of greatest *precipitation*, and therefore of greatest *erosion*, and therefore of constant *restoration of iso-static equilibrium* by upheaval. But this, of course, requires an initiating and more fundamental cause of upheaval, as shown in the next.

5. Thus, causes of upheaval and subsidence of crust, or formation of those greatest inequalities—continents and ocean bottoms—are as follows:

(1) Some interior but very obscure cause, probably unequal radial contraction of the earth during all geological time. (On the principle of isostacy the ocean bottom crust ought to be denser than the continental. This is proved to be a fact.)

(2) Once started by interior causes, whatever these may be, erosion of continents *would continue the upheaval by lightening*, and by sedimentation—the sinking of sea bottoms by loading. This would tend to continue indefinitely. Geology confirms this.

(3) Barometric pressure may affect this slightly directly, but indirectly very greatly, by producing belts of excessive precipitation, and therefore of excessive erosion.

6. I sympathize deeply with wide generalizations, such as that attempted in the paper (in fact, geologists are accused of being too fond of them); but it is necessary to take a comprehensive view, and especially to go slow.

Lieut. J. P. Finley—Mr. President. This paper is really a geological one, and in that respect, as a meteorologist, I am not in a position to criticize it.

The main purpose of the paper is to establish certain geological occurrences, or to attempt an explanation of their supposed relation to certain meteorological conditions, and the appearance of the surface of the earth over a portion of the Northern Hemisphere.

There is no question in my mind as to the location of the northern cyclonic belt—the position of the storm line across the continent of North America. All storms move from west to east. The word *storm*, however, is not a proper term to apply here, because it has been used for a hundred years to indicate wind force and not systems of atmospheric circulation.

There are two lines of cyclonic movement on the continent of North America, only one of which has been referred to in this paper. The other forms a parabolic curve over the Gulf of Mexico, starting from the West India Islands, passing northwestward over the Gulf into the Mississippi Valley and thence northeastward off the New England coast. It is a belt of cyclonic movement confined to certain portions of the year, and involves those disturbances which are known as West India hurricanes. But this is hardly the proper term to apply to them. A hurricane is nothing more or less than a straight-line wind, a term applied in wind scales to represent the maximum force or velocity of moving cur-

rents of air. It is therefore improper to apply it in describing any system of circulation in the atmosphere.

The relation of the Gulf line of cyclonic movement to the geological formation of that region, I am not prepared to discuss. This paper has omitted any reference to this belt of cyclonic movement and its effect upon the contour of the land areas over which it passes.

Along the line of cyclonic movement, wherever that may be, I should judge the effect upon the surface of the earth in denudation or in erosive action would result almost entirely from precipitation. We know that during very heavy cyclonic movements across the continent, the effect upon the river systems is very marked, and that great quantities of alluvial detritus are carried down into the rivers, changing their beds, and in some respects the configuration of large areas of country.

I cannot recollect the year (probably about 1878) in which observations were begun to note the effect upon the river systems of the country of the periods of greatest cyclonic activity. It is a matter to which the Signal Service is giving considerable attention, a corps of observers having been established for the purpose of gathering information upon the subject. These facts would lead, of course, back to the point that the most prominent effects of cyclonic movement over land areas are those resulting from precipitation.

There is one portion of the paper which refers to a class of cyclones by the term *monsoon*. I am aware of the fact that this term is used a good deal in that respect, but I think it is a misapplication. The word monsoon should only apply to a local periodical movement of the air, either from a land area to an area of water or the reverse. It is really not a great system of atmospheric circulation which we designate by the term

cyclone, but rather an attendant feature of those disturbances. In attempting to define the two great classes of atmospheric disturbances, the word monsoon would not be employed.

We could say that the winds which are popularly called trade winds here in San Francisco, are monsoon in character, but we could not apply that term to the cyclonic and anti-cyclonic disturbances which give rise to those winds. They are not the trade winds of the North Pacific but their monsoon character has given rise to a misapplication of the term.

No matter where these disturbances are formed, all cyclonic movements have features in common. This statement applies to all parts of the northern hemisphere, as far as our observations have been made. The signal service has made, in conjunction with observers throughout Europe, a series of observations covering a period of ten years, which have been discussed under the head of International Meteorology, and a series of monthly publications covering the entire period have recently been completed at the Central office at Washington. In that investigation it has been found that cyclonic movements were continuous from west to east, and in some instances we were able to trace the cyclonic disturbances from their source over the Japan Current back to the Japan Current again. In other words, the atmospheric eddy passed around the world. The charts for a large portion of the northern hemisphere were not very perfect, owing to the great distances between stations. We are often able to trace and secure the identity of a cyclonic disturbance without any evidence of precipitation. The change of the barometer would indicate the continuity of the cyclonic circulation of the atmosphere, although precipitation

might be entirely absent. I suppose the popular mind would consider that the cyclone had disappeared, unless there was precipitation somewhere within its area, but that is not at all required in order to distinguish the identity of the disturbance. Very frequently we have cyclonic disturbances of considerable energy that give rise to large precipitation in the North Pacific Coast region, but after passing inland into Montana and Wyoming are entirely free from precipitation, and are then only traceable by barometric fluctuations. These are usually noted in twelve and twenty-four hour changes and departures from the normal, and would hardly be noticeable on an ordinary chart tracing the lines of cyclonic movement.

This fact shows the value of a long series of observations made systematically and very carefully. In meteorology an observation omitted is lost forever. Therefore it has been considered extremely important that the weather work of the signal service should be maintained by a corps of observers who can be held to their posts of duty irrespective of any trouble, no matter whether it involves war, illness or spread of disease, such as cholera or small-pox. We have held our men to their stations even though death came and removed their families. If the observer was removed by contagious disease we immediately replaced him, considering the continuity of the observations at a station superior to even human life.

Although this paper involves many technical questions in geology, yet the interest of the meteorologist is awakened and his attention held by the able and ingenious effort of the author to show a most unique and probable relationship between geological forces and atmospheric changes. The idea is entirely new to me, and I am of the opinion that it has never before been presented or

discussed. The probability that geology may assist in formulating laws concerning the distribution, frequency and force of the general disturbances of the atmosphere, presents to view a most inviting field for investigation.

The subject is worthy of attention, and it is hoped that the leading meteorologists of the world may have opportunity of considering the views expressed by Mr. Manson.

Just now there is great activity in meteorological investigation throughout the world, and attention is centered upon the United States as the field of greatest opportunity for new developments in weather science. The work of the U. S. Weather Bureau needs to be directed towards greater sympathy with kindred sciences. Meteorological research should incline towards all departments of science where there is any evidence of mutual gain. Mr. Manson's paper is very opportune in this respect, and will, I feel confident, be greeted with much satisfaction by those who are laboring for the most liberal development of the science of meteorology.

Very fortunately for Mr. Manson, the meteorology of his paper embraces important facts and well established views. His plan of presentation is well invested but necessarily brief. His attention, however, has been directed to the least violent of the two belts of cyclonic activity in North America. It is important to state, relative to the Gulf belt, that its activity is most pronounced during certain months of the year, viz: from August to November inclusive. The Northern belt is active throughout the year. There is no question as to the direct erosive effect of atmospheric precipitation. Some soils and rocks are more easily affected than others, but continual dropping compels the hardest substance to yield.

Changes in temperature and consequent changes in the moisture of the earth and atmosphere give rise to disintegration, and materially aid the denuding effect of running water. Precipitation and temperature are certainly the most important atmospheric agencies which leave physical traces of cyclonic activity. Their action is readily discernible and susceptible of proof. Not so, however, with changes in barometric pressure. There is not only no direct proof of any physical modification of the earth's surface due to barometric fluctuations, but it is difficult to conceive that there could be. Even the element of time does not avoid the insufficiency of this agency to account for changes in the earth's crust. Fluctuations in atmospheric pressure are generally gradual, even along the belts of greatest cyclonic activity. A barometric change of one inch at any place usually requires more than thirty-six hours for its accomplishment.

The greatest changes in barometric pressure have not been reported from the northern cyclonic belt, but rather from the Gulf belt. They are sometimes very marked in the vicinity of Nova Scotia and New England. It would appear, therefore, that the physical traces of cyclonic activity ought to be very evident along the course of the West India disturbances.

The fiftieth parallel is really the region of the most marked *anti-cyclonic* activity. The *highest* barometric pressures recorded by the Signal Service have been reported from stations in that latitude, while the *lowest* have occurred along the Gulf and Atlantic coasts. The region of greatest precipitation is not coincident with the northern belt of greatest cyclonic activity. It is heaviest along the Gulf and Atlantic coasts, and on the Pacific Coast from Alaska southward to Washington.

It is true that the great river systems of the Northern Hemisphere rise along the fiftieth parallel, but their connection in this respect with atmospheric changes of pressure and temperature is hardly that of cause and effect. Could physical and geological conditions along the fiftieth parallel have decided the question as to whether cyclonic disturbances actually maintain their identity from the Pacific to the valley of the Mississippi? I think not. It required the synoptic weather chart in its best form to divulge that secret.

Along this parallel, after leaving the immediate coast of Washington and British Columbia, atmospheric precipitation is extremely limited, and therefore its corresponding erosive effect must be diminished. The location of the northern belt of cyclonic activity along the fiftieth parallel is not due to any peculiar geological formation or topography of the interior of North America, but, on the contrary, to the existence of permanent and extensive sources of heat and moisture in the great warm river of the North Pacific. The daily variability of temperature is less in Oregon and Washington than in any other part of the country; but eastward of this region, from Montana to the coast of Labrador, the greatest extremes of temperature are experienced. The effect of these changes upon the earth's surface is doubtless considerable, and it would be a subject of much interest and value to systematically observe and record such influences.

After leaving British Columbia, cyclonic disturbances from the Pacific would dissipate before reaching the Atlantic were it not for the heat and moisture thrown off and carried northward from the Gulf and Gulf Stream. Many of the cyclones would not survive to the Great Lakes. Reverse the source of the Japan Current so that

it would flow northward along the California Coast, and as a result the belt of cyclonic movement would be shifted from its present location southward to between the thirty-fifth and fortieth parallels. Such a physical change would work a wonderful modification of the climate and vegetation of the Middle and Southern Plateau Regions. What would be the geological effect? Is there any evidence to show that the thirty-seventh parallel has not been the course of cyclonic activity from the Pacific at some stage of our earth's existence? How far can geology assist meteorology in solving the problems of atmospheric circulation? What can be the practical outcome of this discussion? If any at all, it is perhaps more likely to benefit meteorology than geology. But generalizations, however broad, are oftentimes the harbingers of important truths, that can not be crystallized without a good deal of hard pioneering.

Mr. von Geldern—Mr. Manson's paper has interested me very much, and although I do not consider atmospheric pressure as one of the principal factors in the formation of continents, I am quite ready to attach to it more importance than I had hitherto given it. While the active cause of the plastic condition of the earth's crust is probably subterranean, and considerably beyond our comprehension, secondary causes are to be looked for in physical forces manifest on the surface, such as volcanic action, the mountain building forces, actions of the sea, and climatic effects, to which the cyclonic belts may be reckoned. While every factor is important, and, regarded as a physical force, of a magnitude beyond human comprehension, each in itself, however, plays but a small part in nature's economy in moulding the skin of the earth.

The result as we now behold it, is probably brought

about by many closely related and interdependent cosmic forces, that have been in operation from the infancy of the globe, and continue to affect its surface, in the same or in a modified degree, as the world grows older. It would be difficult to say that any one of these secondary causes is of greater importance than another, and what the result would have been if any one were lacking.

That the pressure of the sea of air and its oscillations affect the surface of the earth directly, and more particularly indirectly, by resulting precipitations, may be conceded.

The relation of the weight of the air to the form of the land is mentioned by Alexander von Humboldt in discussing atmospheric pressure, but he speaks of it in this sense: that the geographical position of isobarometric lines yield important conclusions regarding the influence exercised by the form of the land and the distribution of seas on the oscillations of the atmosphere.

The consideration of physical forces, in the light of the physicist, is always of interest to the engineer and should be encouraged.

Mr. Manson—Prof. LeConte makes a very striking and plausible point in calling attention to the lessening of pressure by erosion, and consequent lifting, along the zone of cyclonic movement; and the depression of remote areas by the resulting sedimentation.

The writer cannot however agree with Professor Le Conte in his view of the inoperative character of a cause by reason of its not being cumulative; many causes recognized in both cosmology and geology as still potent, are now the reverse of cumulative. The concentration of a vast ice sheet, with its line of dispersion along the zone of maximum precipitation was cumulative in its effects for a long period after its commencement. This

was possibly a constant, and later a decreasing cause of glacial erosion; its activity as a cause did not end when it ceased to be cumulative.

Whatever may have been the components of the atmosphere during that period of the earth's evolution when its surface temperature was strongly influenced by its interior heat, as soon as solar heat became a potent source there must have been an equatorial torrid zone, from which the atmosphere and water circulated towards the lesser heated polar regions. This circulation influenced by the rotation of the earth, would establish the polar geo-cyclone referred to by Prof. Le Conte; but around the margin of this geo-cyclone would be the great cooling area, where warm and cold currents met, and hence this margin would be the region of maximum cyclonic energy and precipitation.

The writer does not contend that the causes mentioned are the only, nor even the prime causes of maximum plateau or continental elevations, but that these causes have not heretofore been pointed out, and that their action is traceable by lines of maximum upheaval and denudation.

That the great plateau elevations of the northern hemisphere occur along the belt of maximum cyclonic movement is indisputable; that the summits of these plateaus are the locus of maximum exposure of the geologically oldest rocks is likewise indisputable. There must be definite causes for these facts. If those assigned by the writer are erroneous or inadequate, the true or additional causes have not yet been pointed out.

The climate prior to the glacial epoch was more equable than during or subsequent to that epoch, as evidenced by the fauna and flora of the Paleozic and Mesozoic eras. Hence the atmospheric phenomena of those eras were more uniform and less violent, but still potent.

The track of gulf cyclones (or West India hurricanes) was not overlooked by the writer, as thought by Lieut. Finley. These cyclones have not had the great periods of activity belonging to those traversing the globe about latitude 50°. Their movements are more erratic, and their violence is concentrated upon a comparatively small area. "They could not have been established until *after* the upheaval of the continents." Nor can the writer agree as to the parabolic nature of their path —certainly no such curve could be laid out upon the surface of a sphere.

These storm movements are probably the general northerly and easterly circulation concentrated by physical and meteorological conditions along certain lines, and are unquestionably more recent than those into whose general track they are drawn off the coast of Nova Scotia and New England.

The problematic effects of a reversion of the Japan Current are foreign to the objects of the paper under discussion. The writer is not aware of any traces of cyclonic movement about latitude 37° N., all of his studies pointing conclusively so far to the permanence of such movement about latitude 50° N.

TECHNICAL SOCIETY OF THE PACIFIC COAST.

SAN FRANCISCO, CALIFORNIA.

INSTITUTED APRIL, 1884.

PROCEEDINGS.

(VOLUME VIII. No. 1.

MINUTES OF MEETINGS.

ANNUAL MEETING.

January 23d, 1891.

Called to order at 8:30 P. M. by the President.

Amendments to the Constitution, as proposed, were read by the Secretary, and each article as read was, upon motion, recommended for adoption.

ARTICLE VI.

To change the paragraph:

"A *Member* shall be one qualified to design as well as direct technical work, and who shall have been engaged professionally in the practical application of science for a period of seven years, or for a period of five years if a graduate of a college or technical school."

to read:

"A *Member* shall be one qualified to design as well as direct technical work, and who shall have been engaged professionally in the practical application of science for a period of five years, or for a period of three years if a graduate of a college or technical school of recognized standing."

ARTICLE XII.

To change the words "Any vacancy occasioned by resignation or otherwise, must be filled at the next regular meeting of the Society after notice of said vacancy, by ballot and simple majority."

as follows:

"Any vacancy occasioned by resignation or otherwise may be filled at the next regular meeting of the Society, after notice of said vacancy by ballot and simple majority, or in the case of temporary absence, by appointment by the president or the active presiding officer, of a substitute to fill the temporary vacancy."

ARTICLE XIX.

To change the words "The annual meeting for the election of officers and hearing the annual report shall be held three weeks after the regular meeting of the month of January."

to read:

"The annual meeting for the election of officers and hearing the annual report shall be held two weeks after the regular meeting of the month of January."

Also to strike out the words: "This estimate shall be binding on the Society, unless a two-thirds vote of all members decide otherwise. Absent members can vote by letter."

ARTICLE XXIV.

To strike out the whole clause:

"The Board of Direction may recommend to the next regular meeting an application for exemption from the payment of annual dues of any member, who, from ill health, advanced age or other good reason, is unable to pay such dues; and the Board of Direction may, if so authorized by the vote of the regular meeting, remit the whole or part of dues in arrears."

and substitute:

"Upon application being made in writing to the Board of Direction for the exemption from payment of annual dues by any member who, from ill health, advanced age or other good reason, is unable to pay such dues, the Board of Direction shall consider the matter at their next meeting, and by a unanimous vote may remit the whole or part of the dues in arrears."

The Treasurer submitted the following detailed report of the receipts, expenditures, and financial standing of the Society:

Balance on hand, January, 1890	$ 521 01
Collections	1,331 50
Sale of Transactions	9 85
Total	$1,862 36

DISBURSEMENTS, AS PER VOUCHERS.

For Secretary, 1889	$ 150 00
For Secretary, part of 1890	250 00
Room rent	180 00
For office, stationery, postage and expressage	147 98
Collector's percentage	65 61
Printing Transactions, including engraving	650 00
Job printing, bookbinding, and library expenditures	337 79
	$1,781 38
Balance, cash on hand January, 1891	80 98
Total	$1,862 36

The report was ordered received and referred to the new Finance Committee at the next regular Directors' meeting.

The Secretary submitted and read the following report on the present membership and the transactions of the Society:

The present total membership is 149, as follows: Honorary members, 1; members, 137; juniors, 1; associates, 10—total, 149. Of these 105 are resident, and 44 non-resident members.

A geographical distribution places 105 in San Francisco and vicinity, 25 in other parts of the State, 3 in Nevada, 1 in Idaho, 1 in Washington, 1 in Oregon, 2 in Colorado, 1 in Minnesota, 1 in Massachusetts, 1 in Illinois, 1 in West Virginia, 3 in Hawaii, 1 in England, 3 in Africa.

Professionally divided, there are 57 civil engineers, 34 mechanical engineers, 21 mining engineers, 4 architects, 2 builders, 1 naval architect, 1 electrical engineer, 1 surveyor, 2 professors of University, 6 technologists, 4 military engineers, 2 instrument makers, 4 chemists, 10 associates of various professions.

During the year 1890 the Society increased in membership as follows: Admitted, 48; reinstated, 3—total, 51. Resigned, 1. Gain, 1890, 50. There are 41 members, 1 junior, 8 associates—50.

Professionally divided: Civil engineers, 10; mechanical engineers, 20; mining engineers, 3; architects, 2; surveyors, 1; naval architect, 1; technologists, 3; instrument makers, 2; associates of various professions, 8—total, 50.

Membership of Society January 1st, 1890: Members

and associates, 101. Increase in 1890, 50—total, 151. Deaths during 1890, 2. Present membership, 149.

Members deceased, 1890: Emil Adler, of Portland, Oregon; Geo. C. Knox, of Los Angeles, Cal.

Number of regular meetings held during year, 12; Directors' meetings, 9; special meetings, 1. Number of papers read, 11; number of papers read by title, 1; number of addresses made, 4.

Papers were published in printed proceedings of the past year on thirteen different subjects: Civil engineering, 5; mechanical engineering, 4; pure mathematics, 1; technological, 1; mining engineering, 1; electrical engineering, 1—total, 13.

"This report shows how encouraging the work of the Society has been during the past year, and how much could be accomplished in this laudable undertaking if every member would assist to the best of his ability to promote the welfare of the Society. Much remains to be done to bring it into prominence, and to make it a factor that should be considered in many business enterprises on the Coast. With the coming year work is in contemplation that it is hoped will ultimately lead to the desired end. The time has come and there is room for a Technical Society on the Pacific Coast, and we have good material here from which to build it. The foundation is laid, and if we fail in the superstructure the fault will be our own."

The election for officers for the ensuing year being in order, the President appointed tellers to open and count the votes with the Secretary.

After a count of ballots, the following ticket was declared elected: President, John Richards; Vice-Presi-

dent, Luther Wagoner; Treasurer, Geo. F. Schild; Secretary, Otto von Geldern. Directors, Hermann Kower, Ross E. Browne, C. E. Grunsky, Jas. W. Reid, Alpheus Bull.

A meeting of the Board of Directors was ordered for Monday January 26th, at noon, to be held at the office of President Richards.

Adjourned.

OTTO VON GELDERN,
Secretary.

REGULAR MEETING.

February 6th, 1891.

Called to order at 8:30 P. M. by Mr. C. E. Grunsky, Acting Chairman.

The minutes of the last regular meeting were read and approved.

The following gentlemen were elected to membership:

Members—John L. Heald, Edward N. Robinson, Edward Hooper, Joseph C. Sala.

The following names were proposed:

For members—Robert Stevenson, civil engineer, proposed by B. McIntire, Chas. Koefoed and Hubert Vischer; G. A. Atherton, county and city surveyor, Stockton, Cal., proposed by Hubert Vischer, Luther Wagoner and Otto von Geldern; Edward Eugene Tucker, civil engineer, Stockton, Cal., proposed by Hubert Vischer, C. E. Grunsky and Otto von Geldern.

For juniors—Jas. T. Ludlow, mechanical draughtsman, proposed by B. McIntire, Chas. J. Koefoed and Otto von Geldern; Halfdan Sommerfeldt, mechanical draughtsman, proposed by C. A. Stetefeldt, H. C. Behr and Geo. F. Schild.

For associate—Leon A. Corneille, proposed by W. Leichter, A. E. Chodzko and H. C. Behr.

The proposed amendments to the Constitution, as read before the annual meeting, were again brought to the notice of the Society, and read by the Secretary.

Mr. Grunsky reported the present condition of the proposed bill to license surveyors and the progress thus far made in a legislative way at Sacramento. He stated that the first section of the bill, making it unlawful for any one to engage in land surveying and make a charge therefor, unless he has first secured a surveyor's license, had been declared unconstitutional, and had to be stricken from the bill.

The Secretary read a paper submitted by the President, Mr. John Richards, on the subject of "Abrasive Cutting in the Mechanic Arts."

Adjourned.

REGULAR MEETING.

March 6, 1891.

Called to order at 8:30 P. M., by the President.

The minutes of last regular meeting were read and approved.

The following gentlemen were elected to membership:

Members—Robert Stevenson, G. A. Atherton, E. C. Tucker.

Juniors—Jas. T. Ludlow, Halfdan Sommerfeldt.

Associate—Leon A. Corneille.

The ballots on certain amendments to the Constitution, proposed at the Directors' meeting, October 30th, and read before the annual meeting, January 23d, were

counted, resulting in a unanimous vote in favor of their adoption.

Mr. A. W. Stahl, Naval Constructor, U. S. Navy, then addressed the members on the "Modern Theory of Ocean Waves," after which a discussion of the subject followed.

A vote of thanks for Mr. Stahl was passed.

Adjourned.

REGULAR MEETING.

April 10th, 1891.

Called to order by the Vice-President, Mr. Luther Wagoner.

The minutes of the last regular meeting were read and approved.

The following names were proposed:

For members—R. Hinchliffe, mechanical engineer, proposed by H. C. Behr, A. E. Chodzko and W. Leichter; Leonard J. Gates, mechanical engineer, proposed by L. A. Corneille, A. E. Chodzko and Otto von Geldern; Guy Sterling, civil engineer (North Yakima), proposed by Otto von Geldern, C. E. Grunsky and Geo. F. Schild; Jerome Newman, civil engineer (Tacoma), proposed by Prof. Frank Soulé, Hermann Kower and Otto von Geldern; Harry I. Willey, civil engineer, proposed by C. E. Grunsky, Otto von Geldern and Geo. F. Schild; Louis Falkenau, chemist, proposed by John Richards, H. C. Behr and Geo. F. Schild.

For junior member—Franklin Booth, graduate College of Mines, University of California, proposed by Ross E. Browne, Geo. F. Schild and H. C. Behr.

For associate—E. C. Sessions, of Oakland, proposed by John Richards, Geo. F. Schild and H. C. Behr.

The Secretary read a paper written by Mr. S. Harrison Smith, on the subject of Street Pavements, which led to a general discussion. The majority of the members participating expressed a most favorable opinion of the bituminous rock pavement as that best adapted for the ordinary traffic, under the condition, however, that a proper and adequate foundation be furnished for it, and that the skin be kept in thorough repair. The discussion was carried on at length by a number of prominent members.

Mr. A. T. Herrmann, being called upon, related the details of the passage of the bill to license surveyors, and explained the difficulties under which the committee having the matter in charge accomplished the passage of the Act as it now stands.

It was ordered, upon motion, that the thanks of the Society be expressed to the committee for the useful work performed, as well as to those members of the State Legislature who befriended the Act and assisted in its becoming a law.

The Secretary was instructed to communicate this resolution to the various parties.

It was further ordered that the Society print in its proceedings the "Act to define the duties of and to license Land Surveyors" in full as passed by the last Legislature.

Adjourned.

AN ACT

TO DEFINE THE DUTIES OF AND TO LICENSE LAND SURVEYORS.

The People of the State of California, represented in Senate and Assembly, do enact as follows:

SECTION 1. Every person desiring to become a licensed land surveyor in this State must present to the State Surveyor-General of this State a certificate that he is a person of good moral character; also, a certificate signed by three licensed surveyors, or a certificate signed by the Board of Examining Surveyors, provided for in section five of this Act, which certificate shall set forth that the person named therein is, in the opinion of the person signing the same, a fit and competent person to receive a license as a land surveyor, together with his oath that he will support the Constitution of this State and of the United States, and that he will faithfully discharge the duties of a licensed land surveyor, as defined in this Act.

SEC. 2. Upon receipt of such certificate and oath by the State Surveyor-General, it shall be his duty to forthwith issue to such applicant a license without charge, which license shall set forth the fact that the applicant is a competent surveyor, or that he has had at least two years' experience in the field as surveyor or assistant surveyor.

SEC. 3. Such license shall contain the full name of the applicant, the technical institution from which he is a graduate (if he be a graduate), or if he is not a graduate, the fact must be stated in the license, his birthplace, age, and to whom issued, the name of the person upon whose certificate the license is issued, and the date of its issuance.

SEC. 4. All papers received by the State Surveyor-

General, on application for licenses, shall be kept on file in his office, and a proper index and record thereof shall be kept by him, and a list of all licensed land surveyors shall be kept by him, and he shall monthly transmit to the County Recorder of each county in this State a full and correct list of all persons so licensed, and it is hereby made the duty of such Recorders to keep such lists in their offices in such a way as they may be easily accessible to all persons.

Sec. 5. Within twenty days after the passage of this Act, the Governor shall appoint three surveyors in good standing, members of the Technical Soctety of the Pacific Coast, and two other surveyors in good standing, not members of such Society, as a Board of Examining Surveyors, who shall conduct such examinations and make such inquiries as to them may seem necessary to ascertain the qualifications of applicants for surveyors' licenses.

Sec. 6. A majority of the Board of Examining Surveyors shall meet on the first Friday of each month during their term of office, in the rooms of the Technical Society of the Pacific Coast in San Francisco, and at such other times and places as they may select. The members of the Board shall hold office for the term of one year from the date of appointment, and shall serve without compensation.

Sec. 7. Every licensed surveyor shall have a seal of office, the impression of which must contain the name of the surveyor, his principal place of business, and the words, "Licensed Surveyor;" and all maps and papers signed by him, and to which said seal has been attached, shall be *prima facie* evidence in all the Courts of the State.

Sec. 8. Surveyors' licenses, issued in accordance with this Act, shall remain in force until revoked for cause, as hereinafter provided.

Sec. 9. Every licensed surveyor is authorized to administer and certify oaths when it becomes necessary, to take testimony, to identify, or establish old or lost corners; or, if a corner or monument be found in a perishable condition, and it appears desirable that evidence concerning such corner or monument be perpetuated; or whenever the importance of the survey makes it desirable, to administer an oath for the faithful performance of duty to his assistants. A record of such oaths shall be preserved as a part of the field notes of the survey.

Sec. 10. Every licensed surveyor is hereby authorized to make surveys relating to the sale or subdivision of lands, the retracing or establishing of property or boundary lines, public roads, streets, alleys, or trails; and it shall be the duty of each surveyor, whenever making such surveys, except those relating to the retracing or subdivision of cemetery or town lots, whether the survey be made for private persons, corporations, cities, or counties, to set permanent and reliable monuments, and such monuments must be permanently marked with the initial of the surveyor setting them.

Sec. 11. Within sixty days after a survey relating to the sale or subdivision of lands, the retracing or establishing of property and boundary lines, public roads or trails, original cemetery or town sites and their subdivisions has been made by a licensed surveyor, he shall file with the Recorder of the county in which such survey or any portion thereof lies, a record of survey. Such record shall be made in good, draughtsmanlike

manner, on one or more sheets of firm paper of the uniform size of twenty-one by thirty inches. This record of survey shall be either an original plat or a copy thereof and must contain all the data necessary to enable any competent practical surveyor to retrace the survey. The record survey must show: All permanent monuments set, describing their size, kind and location, with reference to the corners which they are intended to perpetuate; all bearing or witness trees marked in the field; complete outlines of the several tracts or parcels of land surveyed, within courses and lengths of boundary lines; the angles as measured by Vernier readings, which the lines of blocks or lots, if the record relate to an original townsite survey, make with each other and with the center lines of adjacent streets, alleys, roads or lanes, the variations of the magnetic needle with which old lines have been retraced; the scale of the map; the date of survey; a proper connection with one or more points of an original or larger tract of land, and the name of the same; the name of the grant or grants, or of the townships and ranges within which the survey is located; the signature and seal of the surveyor; *provided*, that nothing in this section shall require record to be made of surveys of a preliminary nature, where no monuments or corners are established.

Sec. 12. The record of surveys thus filed with the County Recorder of any county must be by him pasted in a stub-book provided for that purpose, and he must keep a proper index of such records, by name of owner, by name of surveyor, by name of grant, city or town, and by United States subdivisions, and he shall make no charge for filing and indexing such records of surveys.

Sec. 13. Upon the failure of any licensed surveyor

to comply with the requirements of this Act, and the furnishing of satisfactory proofs of such fact, the State Surveyor-General must revoke his license, and no other license shall be issued to him within one year from such revocation. A violation of section eleven of this Act shall be a misdemeanor, and any person convicted of such violation shall be punished by a fine not to exceed more than one hundred dollars, or imprisonment in the county jail not exceeding thirty days.

Sec. 14. In case said Board shall refuse to meet and examine applicants for licenses, as in this Act provided, and issue to such applicants the certificate or certificates mentioned in this Act, if such person be a fit and competent person to receive the same, they may be compelled to do so by mandamus, and if, upon the hearing of such mandamus, it appears that they have willfully and wrongfully refused to examine any applicants, or to issue him a certificate when he is entitled to the same, such Board so refusing or failing, shall be jointly and severally liable for all costs of said mandamus proceeding, including attorney's fee of five hundred dollars, and shall be so jointly and severally liable to any person aggrieved by such refusal in the sum of five hundred dollars, as fixed, settled, and liquidated damages, which may be recovered in any Court in this State, and the judgment (if it be for plaintiff) in mandamus shall be *prima facie* evidence of such injury and damage in any action which may be brought to recover damages under the provision of this Act.

Sec. 16. All that part of the Code of Civil Procedure of this State relating to mandamus is hereby made applicable to the provisions of this Act, and all proceedings in mandamus under this Act shall be in accordance therewith.

SEC. 17. This Act shall take effect on the first day of July, eighteen hundred and ninety-one.

The Governor of the State of California subsequently appointed the following Board of Examiners:

Luther Wagoner and S. Harrison Smith of San Francisco, L. F. Bassett of Redding, Shasta Co., members of the Technical Society, Fred Eaton of Los Angeles, and R. Dittrich of San José.

REGULAR MEETING.

May 1st, 1891.

Called to order at 8:30 P. M., by the President.

The minutes of the last regular meeting were read and approved.

The following gentlemen were elected to membership in the Society:

Members—R. Hinchliffe, Leonard J. Gates, Guy Sterling, Jerome Newman, Harry I. Willey, Louis Falkenau.

Junior member—Franklin Booth.

Associate—E. C. Sessions.

The following names were proposed:

For members — Frederick Tardif, marine engineer, proposed by J. P. F. Kuhlmann, H. C. Behr and Geo. F. Schild; Albert Van der Naillen, civil engineer, proposed by Otto von Geldern, Frank Soulé and Geo. F. Schild; J. M. Cunningham, mining engineer, proposed by Luther Wagoner, H. C. Behr and Otto von Geldern; E. J. Shrader, mechanical engineer, proposed by H. C. Behr, Geo. F. Schild and John Richards.

The Secretary read a notice calling attention to the

benefit that would be derived by reducing the dues of the associate members, stating his reasons for such a change, and proposed that Article VII of the By-Laws, prescribing a fee of $5, and yearly dues of $12 for an associate member shall be changed so as to read: *$6.00 yearly dues without an admission fee.*

Mr. R. Hinchliffe then read a paper entitled, "Hall's Hydro-Steam Elevator." The discussion of the subject was ordered postponed until the next regular meeting.

Mr. F. Gutzkow exhibited a steam injector, machine-shop made, for raising acid liquids, an invention of his, which he described to the Society.

Mr. W. N. Anderson, of San Rafael, brought to the notice of the members an improvement in passenger elevators, consisting of sets of self-opening and closing double doors, intended to shut off the draught in the elevator shaft. He successfully manipulated a model of this device.

Meeting adjourned.

REGULAR MEETING.

June 5, 1891.

Called to order at 8:30 P. M., by President John Richards.

The minutes of the last regular meeting were read and approved.

The following were elected members of the Society: Frederick Tardif, Albert Van der Naillen, J. M. Cunningham and E. J. Shrader.

The following names were proposed, and disposed of in the usual way:

For members—Albert Carl Paulsmeier, mechanical engineer, proposed by H. C. Behr, Geo. F. Schild and John Norbom; Charles Henry Congdon, civil engineer (Tulare), proposed by P. J. Flynn, P. M. Norboe and Wm. Irelan, Jr.; B. L. McCoy, County Surveyor Butte Co., proposed by Luther Wagoner, Adolph Lietz and Otto von Geldern; O. C. Sanne, marine engineer, proposed by Geo. F. Schild, John Norbom and H. C. Behr; Lucien N. Sullivan, mechanical engineer, proposed by John Norbom, Geo. F. Schild and H. C. Behr.

For junior—Ernest McCullough, surveyor, proposed by Marsden Manson, A. T. Herrmann and W. G. Raymond.

For associates—S. A. Sanderson, proposed by Luther Wagoner, Otto von Geldern and Geo. F. Schild; Chas. Floyd Barcus, proposed by Luther Wagoner, Frank Reade and Otto von Geldern.

Received the Annual Report of the Chief of Engineers, U. S. Army, 1890, in four parts. Also Annual Reports of the U. S. Coast and Geodetic Survey, 1882 to 1889 inclusive.

Mr. Luther Wagoner submitted the following resolution, which was seconded by Mr. Hermann Kower:

"That Article IV of the By-Laws be changed in Section 1, by striking out the seventh, eighth, ninth and tenth clauses of the order of business; and that the subjects embraced in said clauses thus omitted be considered at a special meeting, to be called by the President, in accordance with Article 1, Section 3 of the By-Laws."

The resolution made by the Secretary at the last regular meeting, to reduce the admission fee and dues of the associate member was brought up, and, upon motion, laid over until the next regular meeting.

Professor Frank Soulé read a paper prepared by Mr. Jerome Newman, civil engineer, a resident of Tacoma, Washington, entitled "Bridge Analysis." It embraced the determination of certain required values in construction by grapho-statics.

After the reading of this paper, a general discussion of the subject of the last meeting of the Society, "Hall's Hydro-Steam Elevator," was in order, and carried on during the remainder of the evening.

Adjourned.

PUBLIC MEETING.

June 19, 1891.

A public meeting was held on this evening, the occasion being an address by Commander H. C. Taylor, U. S. Navy, before the Society, on the subject of the Nicaragua Canal and its relation to the future trade of the Pacific Coast.

After the address, the Hon. Warner Miller, President of the Nicaragua Canal Construction Company, made some remarks, referring to the work thus far done; to the improvement of the entrance of the harbor at Greytown; to the railway built across the swamps of the lower San Juan River; to the extensive and thorough investigations and surveys of the locality, and the trustworthy estimates based thereupon as to the cost of the great enterprise. He described the proposed water-way from the Atlantic to Lake Nicaragua and to the Pacific Coast, touching upon the engineering questions involved in a general way.

Before the close of the meeting, Mr. Marsden Manson offered the following resolution, which was adopted:

"WHEREAS, The Technical Society of the Pacific Coast has watched with interest the development of plans for opening a Ship Canal through Nicaragua, and has made the technical details of the work a subject of study; and,

"WHEREAS, The plans proposed here to-night fully satisfy us of the entire feasibility of the engineering project, and being fully convinced that the completion of this great work will be of the utmost importance to San Francisco, California and the whole Pacific Coast; therefore be it

"*Resolved*, That this Society is warmly in favor of this noble enterprise, and urges upon its members the further and close study of its various features, and the promulgation of the results of such study, and the dissemination of accurate information thus obtained throughout the Pacific Coast and the whole country. And be it further

"*Resolved*, That, recognizing these great features of an engineering work and the influence upon the commerce of the world, that the President of this Society appoint a committee of three members, to be known as the Nicaragua Canal Committee, which shall make the canal its special study, and communicate from time to time to the Society matters of technical and general interest which may arise in the course of the work.

"*Resolved*, That a copy of these resolutions, suitably indorsed, be presented to the Hon. Warner Miller, President of the Nicaragua Canal Construction Company."

(The President subsequently appointed on this committee Messrs. Otto von Geldern, Ross E. Browne and A. T. Herrmann.)

June 20, 1891.

Upon an invitation from Mr. Adolph Sutro, a number of the members of the Technical Society, with the Hon. Warner Miller and Commander H. C. Taylor, U. S. Navy, met at Sutro Heights and were entertained by Mr. Sutro. After a bountiful luncheon, addresses were made until the return of the party to town. The thanks of the Society were tendered Mr. Sutro for the entertainment, which proved a most enjoyable affair to all who participated.

Otto von Geldern,
Secretary.

TECHNICAL SOCIETY OF THE PACIFIC COAST.

SAN FRANCISCO, CALIFORNIA.

INSTITUTED APRIL, 1884.

TRANSACTIONS.

(VOLUME VIII. No. 2.

THE CAUSE OF THE GLACIAL PERIOD

AND

AN EXPLANATION OF GEOLOGICAL CLIMATES.

BY MARSDEN MANSON, C. E., MEM. TECH. SOC. P. C.

[Read September 14th, 1891.]

The cause of the Glacial Period.

"This is confessedly one of the most difficult questions in geology."*

The master minds of the science have advanced many ingenious theories to account for the remarkable and stupendous phenomena presented by the Glacial Period; but their arguments and presentations have not been such as to convince the scientific world of the correctness and sufficiency of the causes assigned.

The mass of evidence proving the reality of such a period has for years been overwhelming, and the traces of its action have been mapped with considerable accuracy. Even the thickness and direction of movement of the great continental ice sheets are approximately known over a large portion of the North Polar and North Temperate Zones, so that scientists have ceased to search with eagerness for further facts in the all absorbing question, the *cause*.

The most prominent of the theories advanced to ac-

* Elements of Geology, Le Conte, p. 575, 2d Ed.

count for the wonderful phases of climate presented by the Glacial Period are:

(1) A decrease in the original heat of the globe.

(2) Changes in the elevation of land and consequent variations in the distribution of land and water.

(3) Changes in the obliquity of the axis of the earth.

(4) A period of greater moisture in the atmosphere.

(5) A variation in the amount of heat radiated by the sun.

(6) A variation in the heat-absorbing power of the sun's atmosphere.

(7) Variations in the temperature of space.

(8) A coincidence of an Aphelion winter with a period of maximum excentricity of the earth's orbit.

(9) A combination of (8) and (2).

Of these theories it may be remarked:

That (1) is a theorem long since demonstrated, but will not account for the disappearance of the Glacial Period.

(2) Is an assumption not entirely warranted by the facts. Variations in elevation cause *local* variations in climate, but are not productive of such wide-spread climatic conditions as are furnished by the Glacial Period. This theory is presented and ingeniously maintained by Sir. Charles Lyell.

(3) Does not account for the great extent of glaciation between the Tertiary Period and the modern Era.

(4) An undeniable corollary of (1), but inadequate in itself to account for the disappearance of the ice envelope.

(5), (6) and (7) are pure assumptions in support of which neither facts, nor other proofs have been brought forward.

(8) is the beautiful and elaborate theory presented

by Dr. James Croll in his profound works, Climate and Time, and Climate and Cosmology. The causes assigned in this theory are inadequate to account for the effects, and necessarily imply a recurrence of glacial periods, of which there are no definite proofs.

(9) is advanced by Mr. Alfred Russell Wallace in his elaborate and valuable work Island Life. He accepts Dr. Croll's theory, with the modification of engrafting upon it changes of land elevations and consequent variations in the distribution of land and water. Of this theory, Prof. Le Conte remarks that it "seems to be by far the most probable yet presented."*

Thus we see:—(*a*) That the astronomer has been called upon to calculate the effect of slight variations in the relative positions, distances and polarity of the earth and sun during vast periods of time. The profound researches of the devotees of that science, have been convincing as to the activity and approximate effect of the variations considered; the accuracy of their deductions cannot be impeached; the past, present and future activity of these influences has been pointed out, but their efficiency to produce a Glacial Period has not been demonstrated.

(*b*) That the student of cosmology has been asked to make an intelligent guess at the variations of the intense cold of interplanetary space, or to prove that the sun at some remote period emitted less heat during the Glacial Period than before or since; or at least, that if emitted, it was conveniently absorbed in the atmosphere supposed to surround that luminary.

(*c*). That the geologist has reckoned upon the upheaval and subsidence of the crust of the earth, because the

*Elements of Geology, 2d Ed., p. 578.

climates and conditions of the Glacial Period would not fit present elevations and present climates, and were inexplicable under present geographical conditions.

Of all the theories so far advanced, none have been presented so as to carry conviction to the searcher for truth, and upon even the most plausible (9) the homely Scotch verdict of "not proven" has been passed by a high authority upon this subject, in his words previously quoted, that it "*seems* to be by far the most *probable* yet presented."

Thus the vast array of facts, collected through the untiring energies and devotion of the students of Geology, has not yet been satisfactorily interpreted. They have proved beyond controversy that in the North Frigid Zone the order of climates has been (1) torrid, (2) temperate, (3) frigid. In the Temperate Zones the order of climates has been more complicated, for whilst this order has been the same as in the frigid, a return to moderate temperatures has been made, but this return has not been along the isotherms antedating the Glacial Period. This is a highly significant fact, and it will be reverted to later. In the Torrid Zone the order has been the same as at the poles, although the mass of facts yet collected has not been so overwhelming as in the Temperate and North Frigid Zones, but in portions, at least, of the Torrid Zone, a tropical climate now prevails over a once glaciated area.* We can thus be warranted in a very justifiable conclusion, that between these extreme variations of torrid, frigid, then torrid again, two temperate periods intervened.

Of the past existence of these climates there is no mistake. Fossil life has recorded the temperatures and

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*Geological Sketches. Agassiz, p. 154, *et seq.*

conditions of past eras over the whole globe. When it was too hot for even torrid plant life, that fact has been unmistakably recorded in the azoic rocks: when the most torrid plant life alone existed, the evidence is indisputable from the equator to the poles: when the climate moderated so as to reach a temperate phase, there are no torrid types, nor glacial striæ to mislead; so also, when the conditions were such as to bury all beneath a mass of ice, of which we have as yet but a meager grasp, the evidences are abundant and convincing, not only as to the intensity of the cold, but as to the approximate depth, extent and lines of dispersion of the continental ice caps thereby produced.

The facts have been collected from every quarter of the globe accessible to man. They cannot be disputed; the only difficulties are to grasp them all, and to interpret them correctly.

GENERAL REMARKS ON CLIMATES.

From the Archaean Era to the present time, surface temperatures or climates have been established under one or the other of two conditions of exposure:

1st. Either earth heat and solar heat combined; or,

2d. Solar heat alone.

There can be no question regarding the dominating power of solar heat in absolutely controlling climates *since* the Glacial Period. If those prior to the culmination of that Period present radical differences, we must attribute such differences to a combination of earth heat and solar heat, for we cannot assume that luminary to have been inactive at any period of cosmological time during which the earth has existed. It is probable that as the supply of energy in that vast source is less than infinite, it is undergoing loss, which loss since the Glacial Period is not appreciable.

In order to fully understand the universal acceptance of the premises to be stated in a general proposition below, the following quotation is introduced from a recent edition of Warren's Physical Geography, edited by Prof. W. H. Brewer, of Yale College.

"ORIGIN OF THE EARTH."

* * * * "At a remote period of its existence, it was a melted fiery ball, surrounded by a thick atmosphere of gases and vapors." * * * "In the course of ages, this fiery ball cooled off, and a solid crust of rock formed on the surface. As the ball shrunk by cooling, the crust wrinkled and cracked, and was thrown into ridges and valleys; meanwhile the waters condensed and ran into the hollows. The interior is still hot, but the crust is now so thick that but little of the interior heat escapes. The present heat of the surface is derived almost entirely from the sun." Page 11 of work cited.

It will also be universally admitted that the solar system is too remote from outside sources for its members to be exposed to any appreciable heat except solar heat, and the resident internal heat of the particular member of the solar system considered. So that in the general study of geological climates but two causes can be recognized.

(1.) A combination of solar and internal heat;

(2.) Solar heat alone.

During the existence of the dual source of heat, the functions of the two were different, and hence the effects of the single source present marked variations from the effects produced during the activity of both sources.

A brief study of this condition will subsequently be presented as explanatory of the variations of climate before and after the glacial period.

THE GENERAL PROPOSITION.

*Given—a heated globe, constituted and circumstanced as the earth, and whose surface temperatures, by reason of internal heat, are above the boiling point of water—to prove that before its surface temperatures can pass under the control of solar heat, the continental areas must be glaciated.**

It will be observed that the surface temperatures of a globe thus situated, are entirely controlled by its own internal or earth heat; for between such surface and any external source, a dense cloud of vapor must exist. The fact that direct or radiant heat rays cannot pass through dense fogs and clouds is well known. Therefore, a globe thus situated can neither give off, nor receive radiant heat. The peculiar function of solar heat, during the existence of appreciable quantities of earth heat, was to warm the upper regions of the atmosphere exposed to its action, thus retarding the action of the cold of space in exhausting the earth heat.

By the conditions of the problem presented, we thus have a globe, having resident in its mass a finite quantity of heat exposed to loss only by means of the gradual expansion of water into vapor, and the exposure of this vapor to the cold of space. This vapor would then, as rain, snow or hail descend all, or part of the way to the earth, receive another increment of heat and ascend as before. A slow process, but exhaustive in time.

Thus the property of water to assume three forms,

*The proposition here stated is applicable to any planet. It is probable that Mars, Venus and Mercury have passed through periods corresponding to our glacial period, and that Jupiter, Saturn, Uranus and Neptune have not reached theirs. The case of Saturn is particularly interesting in the rings surrounding that planet. It is suggested that they may be rings of ice, frozen from the vapor driven off by internal heat; whether this phenomenon is due to an excess of water present upon that planet, or is a phase of all in one period of their climatic development, is left for other discussion.

each of which possesses remarkable qualities with regard to heat and cold, afforded the only means for exhausting the earth heat. As vapor, its storage of heat exceeds that of any other known substance; as snow or ice, its storage of cold is greater than that of any other known substance. The function of solar heat, until this process ceased from the exhaustion of earth heat, was simply conservative; it merely warmed the upper layers of the atmosphere, through whose dense vapor its heat rays could not pass. Light rays penetrate clouds with more facility, and hence reached the earth earlier than heat rays.

The earth may thus be regarded as having been surrounded by a series of spheroidal isothermal shells of mean temperatures. The one next the surface represented a mean temperature of $212^\circ + t^\circ$ Far.; t being positive, and proportioned to the increased pressure of the dense atmosphere existing. Above this isothermal shell were others representing mean temperatures of 90°, 60°, 32° Zero, etc. to $-x^\circ$ Far., the extreme cold of interplanetary space. Between the two spheroidal isotherms of 32° and $-x^\circ$ Far., was one which had a mean temperature of $32^\circ - y^\circ$, and equally exposed to both sources of heat.

That the spheroidal isotherm of 32° Far. was *within* the sphere of influence of earth heat, is proven by the formation of snow or ice at that temperature, both being the resultant of vapor expanded and raised by earth heat to that height as a *minimum*. Moreover, vapor would reach that height as a *minimum*, were solar heat suspended for a definite period, and the earth absolutely exposed to the intense cold of space.

The isothermal shells nearest the earth were spheroidal in shape, and by reason of the conditions, their surfaces were practically parallel with that of the earth; those

most remote from the earth, by reason of solar influence, protruded at the equator and flattened at the poles, so as to be slightly more oblate than the earth; they were sensibly parallel with the spheroidal isotherm now marked by the "snow line." Hence at the equator the direct action of the sun was first felt and established. As the earth heat was a finite quantity exposed to loss, it was in time exhausted. As this loss proceeded, these spheroidal isothermal shells of mean temperatures shrunk in upon the earth, and their contact with its surface marked the zones of corresponding climates prevailing during the dual source of heat. As these climates were independent of direct solar heat, they varied from the climates established by solar heat alone. Hence the marked difference between climates antedating, and succeeding the glacial period. The isotherms preceding this period were dependent almost entirely upon elevation above sea level, fractures and conductivity of the earth's crust; those succeeding it are dependent upon proximity to the equator, elevation above sea level, and the distribution of heat by ocean currents.

At the expiration of a period of time T. the earth lost sufficient heat to cause the isothermal shell of 90° Far. to shrink to the surface except at fractures, and a particularly uniform, moist and highly torrid climate was established, and types of life developed, culminating in the Carboniferous Period.

The crust cooled sufficiently to permit the demarkation of the continental areas, but the cooling did not proceed to that point which upheaved the massive mountain ranges, nor greatly depressed the ocean areas. Therefore, an era of low, flat continents, and shallow hot seas, followed. The life of that period abundantly shows this condition from one pole to the other, and the pre-

vailing temperature is distinctly recorded in the fossil life of the Paleozoic Era.

Light rays reached the surface prior to this time, as evidenced by the development of visual organs in animal life. The greater part of the vapors and gases existing previously in the atmosphere were condensed, and existed upon the surface; the vapors as highly heated oceans, and the gases in various combinations of the mineral and life kingdoms. Now in the oceans thus formed and further enlarged, there was stored up a vast quantity of the original earth heat, by reason of the *high specific heat of water*, from which it was not exhausted until the last moment, and in this process of exhaustion it must have maintained the cloud shield, shutting out solar heat until the last remnant of available earth heat was exhausted. Not only this, the oceans thus formed had a mean temperature of $90^\circ + z^\circ$ Far.; z being a positive increment due to the heat received from the bottoms and sides of the ocean. Not until the bottoms of the oceans were subjected to a degree of cold approximating that to which the continental areas were exposed, could the solid crust be cooled uniformly, and reach that degree of stability suitable to the safety and comfort of the human race.

At the expiration of the period of time T′ the spheroidal isothermal shell having a mean temperature of 60° Far., similarly shrunk to the surface of the earth, and a corresponding uniformly temperate climate was established.

The further cooling of the crust caused its shrinkage, and a consequent greater upheaval of those areas most exposed to loss of heat, the continents. This further shrinkage caused the strata built up during the previous eras to be upheaved and fractured, and the lines of demarkation between oceans and continents were thus more strongly accentuated.

The life developed in the interim, evidences an approach to that of the present, and its wide distribution demonstrates the complete control of the climates of the globe by internal heat. The isothermal lines were entirely at variance with those established by solar heat, therefore the functions of solar heat remained conservative of those operating on the surface during this period also.

The extreme and uniform distribution of fur or hair-covered animals, and of the deciduous and coniferous trees of the Cenozoic Era mark further the control of a source of heat more uniformly distributed than solar heat could possibly be. For reasons previously given, this isotherm also reached continental areas earlier than ocean areas. When the mean temperature of the land was 60° the tepid oceans must have had a mean temperature of 60° + y° Far., y, like z, being positive, and due to increments of earth heat received from the bottom.

At the expiration of this period T′, or at some time, T′ ± a, the isothermal shell of 32° Far. shrunk so as to reach the more elevated portions of the continental areas, and thus established a snow line independent of the influences now establishing and maintaining such snow line. The moment a snowflake reached the earth which the waning earth heat was unable to melt, *the* Glacial Period was inaugurated; and the conditions were such as to favor its extension until the exhaustion of the store of heat beneath the oceans and resident in them, by reason of the high specific heat of water. It will be noted here that whenever, in obedience to the expansive force of this waning earth heat, a particle of water was vaporized, and made the last round of its circulation, it returned to the earth in that form which stored the maximum degree of cold; or, in other words, in that

form which required the maximum amount of solar heat to change. From the moment that snow began to accumulate every remaining vestige of earth heat was available for producing those conditions favorable to glaciation, namely: warm seas, dense fogs and cold continental areas; and every unit of solar energy reaching the upper regions of the atmosphere was available for maintaining those favorable conditions. Glaciation under these conditions would be cumulative until the oceans, exhausted of their heat, were no longer able to supply the moisture necessary to completely shroud the earth from direct solar heat.

At the expiration of the time T″, the isothermal shell having a mean temperature of 32° Far. shrunk in upon the globe and the oceans were exhausted of their store of heat and their bottoms brought in contact with water, having a mean temperature of 31° Far., a temperature approximating that of the ocean depths at present, and of ice in masses.

The isothermal shell 32° Far. having been spheroidal in shape, but more flattened in the prolongation of the axis of the earth than the earth itself, reached polar land areas prior to reaching equatorial land areas, and by reason of the high specific heat of water, reached *continental* areas, prior to reaching ocean areas. Thus the same forces which even before the Eras we have been considering, must have built up upon the surface of the globe mineral forms of surpassing beauty, only to be destroyed and ground down to give place to vegetable and animal forms of wonderful development—these same forces were called upon to well nigh obliterate every living individual of both kingdoms. The efficiency of their work is attested in every zone of life from the equator to the poles.

The exhaustion of the residiuum of earth heat in the oceans and beneath them, could only have been accomplished by the same means as before, and this exhaustion resulted in the preservation of those conditions most favorable to glaciation. When by the chilling of the oceans to about 31° Far. and by the glaciation of continental areas, the air was cleared of obscuring clouds and fogs, the wonderfully uniform series of climates was at an end.

With the dominion of solar heat, began *seasons* of spring, summer, autumn and winter, with the varying changes of the earth's annual round.

The climatic changes during the control of earth heat extended over eras:—

1st. An era of torrid heat.

2d. An era of tropical heat.

3d. An era of temperate heat.

4th. An era of glacial cold.

Each merged gradually into the others, but each recorded its period of existence in unmistakable terms; all shrouded from the direct action of solar heat, and all evidencing by the life produced, the stifling, smothered character of the climate.

That solar heat was shut out from the surface of the earth during the Glacial Period, is geologically recorded in the glaciation of the North Temperate Zone over continental areas where solar energy has removed glacial cold and established in its stead, a mean annual temperature of 40° Far.; and in the torrid zone it has removed glacial cold and established a mean annual temperature of 76° Far. where snow never falls.*

Consequently, in a heated globe, constituted and circumstanced as the earth, exposed to two sources of heat,

*Geological Sketches, Agassiz, p. 154, *et seq.*

internal heat and solar heat, before its climates or surface temperatures can pass under the control of solar heat, the continental areas must be glaciated.

AN EXPLANATION OF GEOLOGICAL CLIMATES.

The dawn of the Archaean Era found the earth a heated globe merging from an era of greater heat. The crystalline character of the earliest rocks demonstrates the high temperature which prevailed upon the surface at that time. Such being the temperature of the surface, it is beyond question that the existence of uncombined water upon it was an impossibility, and as vapor it could only shroud the earth in dense clouds. The earth heat was as effectually shut *in* from loss by radiation, as was solar heat shut *out* from reaching the surface.

As this finite amount of earth heat could only escape by doing *work* in the expanding of water to vapor, vast eras of time must elapse before the work done could exhaust the available heat. The process of exhaustion was further retarded by two causes: 1st, the heating of the outer layers of the atmosphere by solar heat, and, 2d, the low conductivity of the strata of the earth itself. Consequently the climates of the earth, until the final exhaustion of earth heat, were of remarkable uniformity. The faults and fractures of its crust set free additional increments of heat but slowly, so that the torrid, tropical and temperate eras were each longer than the frigid era. It is not improbable that upon certain of the oldest mountains glaciation was inaugurated during the early part of the Cenozoic Era, to slowly disappear from the gradual setting free of earth heat by vast fractures of the crust. This readily accounts for the "Interglacial Periods," which were probably local phe-

nomena antedating the Glacial Period. It is neither logical nor reasonable to interpret the finding of evidences of early local glaciation into a Glacial Period, for glaciations are found now in the Alps and upon certain peaks of the Sierra Nevada, and even in the torrid zone, but they by no means establish the present existence of a Glacial Period.

Once realize that the surface temperatures of the globe were at one Era in the past too high by reason of *internal heat* to permit water to remain upon the surface, and that water possesses the highest specific heat of any known substance, and follow out these facts to their natural and logical conclusion and the whole mystery of geological climates clears up and becomes simple.

Climatic Facts Established by Fossil Life.

It would be impossible in the limits to which it is necessary to restrict this paper to review the vast array of facts which could be brought forward to demonstrate the perfectly uniform, torrid character of the climates of the globe during the Paleozoic Era.

From the 75th degree of north latitude through every range of present climates to the confines of the south frigid zone, the life systems attest the stifling, hot-house character of the heat. The species of plant life and animal life, whether of land or aquatic forms, varied less in the torrid and the north frigid zones than corresponding species upon different continents in the same zone do now. Nowhere below the Permian deposits can fossil life be recognized that does not belong to an ultra tropical type. Such uniformity of temperature is impossible under solar control; and hence can only belong to a climate controlled by earth heat.

This era merged gradually into the Mesozoic Era of

tropical heat; during which the forms of life developed into higher types, and their range of distribution demonstrates the still perfect control of earth heat. One peculiar and significant fact is recognizable in comparing the land forms with the aquatic forms of life. The former developed types more suitable to tropical climates, while the latter held more tenaciously to the torrid types, thus proving the more rapid loss of heat by the continents.

The fossil life of the Cenozoic Era corroborates to a remarkable degree the still perfect control of earth heat. Throughout Greenland, Iceland, Lapland and Spitzbergen, a perfectly uniform and temperate climate existed. The magnolia of the lower Mississippi valley flourished in those localities, in which during the Paleozoic Era, only the gigantic Ferns, Lycopods and Calamites could be found, and where now, only a stunted Arctic growth can exist.

During this era identical types of life existed in all parts of Europe, Asia and America, and a uniformly temperate climate prevailed over the whole northern hemisphere, entirely at variance with the extreme range of temperatures now embraced in that half of the globe.

The control of the waning earth heat was simply dying out, and had reached that stage in which it was no longer able to maintain the high temperatures of previous eras.

Again does the high specific heat of water assert itself, for alongside of these forms, are aquatic fossils indicative of a higher temperature.

The evidence that the high specific heat of water held the last available remnant of earth heat, and thus perpetuated its control of climates, is beyond dispute as presented by the conditions culminating in the Glacial Period.

Whatever may be the doubts, as to the actual date of the Glacial Period, there is no disputing the fact that the evidences establishing the culmination of that Period are found *above* or since the Tertiary, and *below* or before the Modern Era.

Between these two consecutive periods there is abundant evidence from every climate, from every zone of present life, that the continents were glaciated.

Europe and Asia,* North † and South ‡ America,§ Africa || and Australia,¶ all, present glacial striæ, bowlder deposits, and other marked evidences of glaciation at the same period, just antedating the Modern Era, or during the early Quarternary Period.

The ascription of great elevations above sea level during the Glacial Period is natural, and such apparent greater elevation is due to *two* causes during this period, whilst due to only *one* cause during previous eras. As the surface of the earth became subjected to a temperature of 31 degrees Far. under the oceans, and a corresponding temperature under the continental ice caps, contraction and consequent elevation was continued as before; and as snow was piled up upon the continents, water was withdrawn from the oceans; for each million square miles of continental ice cap three hundred feet thick, a corresponding three million square miles of ocean was lowered one hundred feet. The continental

* The Great Ice Age, Geike.

† The Ice Age in North America, Wright.

‡ Geological Sketches, Agassiz.

§ The northern part of South America at present having a mean annual temperature of 76 degrees Far.

|| Geology of South Africa, Stow; Quarterly Jour. Geological Society, Vols. 17 and 18.

¶ Climate and Time, Croll, p. 295.

ice caps already approximately known, were too vast not to have lowered the sea level to a marked degree.

The apparent depression after the Glacial Period is as easily explained. By the melting of the greater portion of the ice caps, and the evaporation of vast inland seas, the sea was approximately restored to the level existing prior to the Glacial Period, thus causing an apparent sinking of the land.

The great difference between climatic conditions prior to and since the Glacial Period, is very marked around inland seas and basins without drainage. Lake Bonneville, Lake Agassiz and Lake Lahontan in the United States, and the greater area once occupied by the Caspian and other seas evidence the superior dampness and rainfall antedating the Glacial Period. During the control of earth heat the oceans were heated to their bottoms, and furnished moisture enough to keep these great depressions full of water, and to support a dense life upon now desert areas. The dry air of the modern era has not only absorbed the water in these vast lakes, and restored it to the oceans, but vast areas have been converted into deserts by the unequal distribution of heat and moisture under solar control.

Thus the Glacial Period, or better, The Great Ice Age, marks the date at which the climates of the globe passed from the control of earth heat to that of solar heat. The great specific heat of water retained in the oceans the energy necessary to maintain the cloud shield shutting out solar heat until both land and ocean areas could be equally cooled and contracted, thus ensuring the maximum degree of stability to the crust. The mysteries of geological climates develop thus into a system beautiful in its simplicity.

RECAPITULATION.

The objects of this paper are to demonstrate:

1st. That in the passage of the earth from an era during which its climates have been controlled by internal heat, into an era during which its climates are controlled by solar heat, a Glacial Period must intervene.

2d. That the direct *cause* of the *Glacial Period* was a combination of the remarkable properties, in relation to heat and cold, possessed by the various forms of water:

As *vapor*, it prevented the loss or receipt of heat by radiation;—

As *water*, by reason of its high specific heat, it retained to the last moment the effective remnant of earth heat;—

As *ice*, it assumed a solid form, storing the maximum amount of cold.

3d. That through all geological time to the culmination of the Glacial Period, solar heat was only conservative of earth heat.

Whether these objects have been attained the scientists of the world must judge.

DISCUSSION.

Mr. C. E. Grunsky—I have followed the reading of Mr. Manson's paper with close attention, and regret that I am not sufficiently familiar with the earliest forms of life to express an off-hand opinion as to whether Mr. Manson's explanation of the cause of the great ice age will harmonize fully with the development of animal and plant life as revealed by geological records antedating the glacial period. However this may be, Mr. Manson is to be complimented on the clear presentation of the results of his study, and on his attempt to explain the

occurrence of the ice age, within the pale of known physical laws.

Having no evidence to the contrary, it is reasonable to presume that while the earth's crust was cooling from a molten state to its present temperature, the elements, oxygen and hydrogen, were continuously combined as water to the same extent as at present; that the nitrogen and oxygen now in the atmosphere were continuously free in about the same quantity as at present, and that certain other gases now forming part of solids and liquids were components of the atmosphere surrounding the earth, before the temperature had been reduced sufficiently to sustain plant and animal life.

The weight of the water upon the surface of the globe is at least twenty times as great as the weight of the atmosphere at present surrounding the earth. This vast weight of water at one time enveloped the earth in the form of vapor, and, according to the known laws of diffusion of gases, steam, nitrogen, oxygen and probably very large quantities of carbonic acid gas, must have been intimately intermingled in the humid atmosphere which was about the earth at the time when the temperature at its surface fell to the boiling point of water.

In this atmosphere water predominated. Falling to the earth it was speedily evaporated; it rose in the form of superheated steam at temperatures possibly in excess of 400° F.; it lost its latent heat into space and was frozen; rotating with the earth, it may have at one time formed a continuous ice ring, floating in space around the earth above the equator.

As the period of intense heat during which the atmosphere may have been as transparent as to-day, was followed by a period during which the radiation of terres-

trial heat was insufficient to maintain the surrounding vapor in a superheated condition, in which period the ice rings above and encircling the earth may have existed, so this period was followed by another, in which the heat supplied by the earth's crust was insufficient to drive off more water than would be required for the great cloud shield impenetrable by solar heat, yet transmitting enough light to permit of the development of the lowest forms of life, as described by Mr. Manson in his paper. At this stage in the cooling process the ice ring encircling the earth, if it ever existed, was disappearing; the outer layers of the atmosphere were cold, possibly full of snow flakes; water poured from the clouds in torrents and great masses of steam rolled back from the warm surface of the earth. Lakes were formed and disappeared in a day; seismic disturbances were frequent and violent; volcanoes were innumerable and active. Unequal heat and unequal cooling at the earth's surface produced great atmospheric disturbances. It was a period of great and violent storms.

Gradually the density of the clouds decrease. Enough light became available at this period, if Mr. Manson be correct in claiming that earth heat was the principal factor in stimulating and forcing the tremendous growth of plants of the carboniferous age, to enable a wonderful development of plant life, which, due to the continuous and uniform temperature then prevailing, extended to all parts of the globe where land was exposed above water.

The radiation of heat was more rapid from land elevated above the surface of the ocean than from the portions of the earth's crust that were submerged. Heat lost by radiation to the clouds, or carried off as latent heat by evaporating water, was not returned, except by

warm rains which fell equally upon land and sea. The theory that this cooling off must have continued while yet the cloud shield was almost without a rift, until average temperature on land fell to near the freezing point and thus made the ice age possible, is a very plausible one, and will, I believe, as soon as it is fully understood by scientists, be recognized as the probable cause of the glacial age.

TECHNICAL SOCIETY OF THE PACIFIC COAST.

INSTITUTED APRIL, 1884.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the statements and opinions advanced in any of its publications.

(VOLUME VIII.—No. 2.)

BRIDGE ANALYSIS.

BY JEROME NEWMAN, C. E., MEM. TECH. SOC. P. C.

(Read June 5th, 1891.)

DEFINITIONS.

In order to find the effect of a *system* of loads on a beam, it is best to determine the influence exerted by a *single* load in every position that it may assume, and from this find the effect produced by the whole number. We shall suppose a load, P, to move from one end of a beam to the other, and determine the influence on any *fixed* section for every position of P. This influence may be the *reaction* at an abutment, the *shearing force* or *bending moment* at any section, etc. We shall call the quantity discussed the "influence-quantity" of the load, P; if we lay off this quantity as an ordinate from a horizontal axis in the line of action of P, and join the ends of these ordinates, we get a line which we call the "influence-line"; the area limited by this line and the axis we shall call the "influence-figure."

SHAPE OF INFLUENCE-LINE.

We shall discuss statically determinate girders only. In this case the point of application and the direction of one reaction and either the point of application or the direction of the other must be given, as in Fig. 1.

If R be the reaction on the left and R_1 on the right, then $Rl = P(l-x)$ and $R_1 l = Px$; now, since the values of

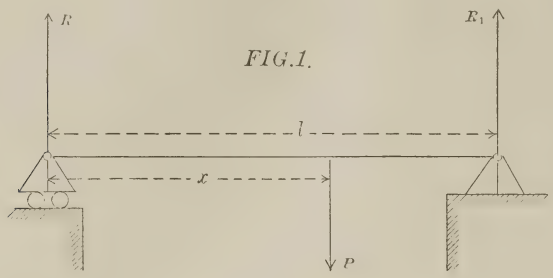


FIG.1.

FIG.2.

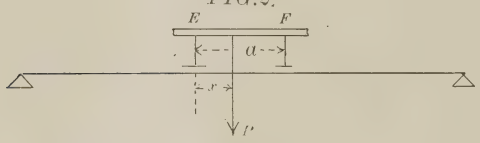


FIG.3

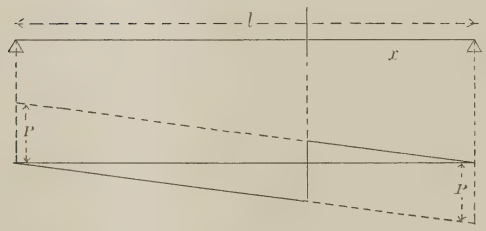
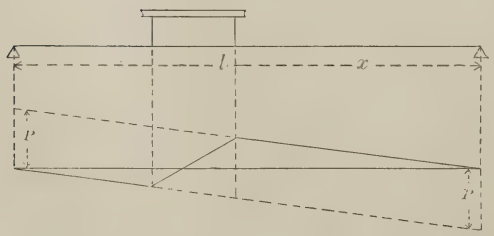


FIG.4.



R and R_1 are of the first degree with respect to x, the influence-lines for the reactions, their components in any given direction and their moments around a fixed point are right lines.

If we suppose the girder divided into two parts by a section, and the load to act directly on it, the only external force on one part is the reaction on this part when the load is on the other; when the load is on the part considered, the external force is the other reaction, with a contrary sign; therefore the influence-line for the external force and its moment around a fixed point is made up of two straight lines.

The strain on any member is proportional to the external force or its moment; therefore the influence-lines for the strains are also composed of straight lines.

In general, therefore, the influence-lines for the reactions, external forces, moments and strains, are composed of right lines, when the reactions are statically determinate and a section through the girder cuts not more than three members.

If the load act indirectly (*i. e.*, by means of cross-girders), assume P to lie between two of the latter; (Fig. 2), the pressure on $E = P\frac{a-x}{a}$, that on E_1 $P\frac{x}{a}$; if Y_1 and Y_2 are the influence-*quantities* for a section between E and F when P acts at E and F respectively, and Y the influence-quantity when P acts between them, $Y = Y_1\frac{a-x}{a} + Y_2\frac{x}{a}$ $\therefore$ the influence line is a right line for any position of the load between the two cross-girders between which the section lies.

Let S be the shearing force, M the moment for any section, and x distance from right abutment; if the load acts directly, and to the right of

the section, $S = P\,\frac{x}{l}$; if to the left, $S = P\,\frac{x}{l} -$ $\therefore$

FIG. 5.

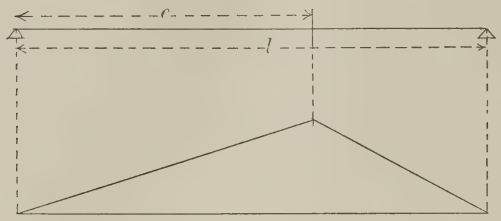


FIG. 6.

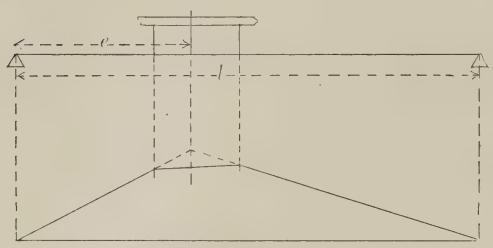


FIG. 7.

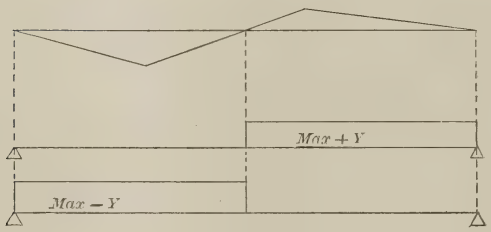
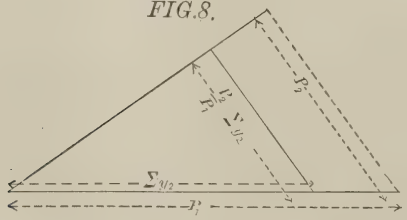


FIG. 8.



the influence-line is as in Fig. 3; for indirect action of the load, the influence-line is shown in Fig. 4.

If the load acts to the right of the section, $M = P\frac{xe}{l}$, e being the distance of the section from the left abutment; if to the left of the section, $M = P\frac{(l-x)(l-e)}{l}$ $\therefore$ the influence-line consists of two straight lines, as in Fig. 5; the influence-line for indirect action of the load is shown in Fig. 6; for a section through a cross-girder, however, the influence-line is the same as if the load acted directly on the beam.

INFLUENCE OF A UNIFORM LOAD.

If p is the load per unit of length of girder, the load on dx is $p\,dx$, and if y is the ordinate of the influence-line for the load *unity*, the influence-quantity for $p\,dx$ is $y\,p\,dx$; for the load on *any* length, Y, the influence-quantity, is $\int p\,y\,dx = Fp$, F being the area of the influence-figure corresponding to the length of the load; if the influence-line be constructed for p per unit, the *area* of the figure is the influence-quantity. The positive and negative maxima of the influence-quantity evidently arise from those positions of the load covering the positive and negative portions of the influence-line. (Fig. 7.)

INFLUENCE OF AN IMMOVABLE SYSTEM OF CONCENTRATED LOADS.

Let P_1, P_2, P_3, etc., be the concentrated loads, and assume each one to occur more than once; then if Σy_1, Σy_2, Σy_3, etc., are the sums of the ordinates of the influence-line (for a load of unity) corresponding to the positions of P_1, P_2, P_3, etc., the influence-quantity of the whole number is $Y = P_1\,\Sigma y_1 + P_2\,\Sigma y_2 + P_3\,\Sigma y_3 + \ldots$ or

$$Y = P_1\left(\Sigma y_1 + \frac{P_2}{P_1}\,\Sigma y_2 + \frac{P_3}{P_1}\,\Sigma y_3 + \ldots\right); \frac{P_2}{P_1}\,\Sigma y_2, \frac{P_3}{P_1}\,\Sigma y_3$$

etc., may be constructed graphically (Fig. 8); and if the influence-line be drawn for P_1, the multiplication of $\left(\Sigma y_1 + \frac{P_2}{P_1} \Sigma y_2 + \ldots\right)$ is rendered unnecessary. Another method is to construct an influence-line for each load and add the ordinates of the lines corresponding to the loads and their positions.

INFLUENCE OF A MOVABLE SYSTEM OF CONCENTRATED LOADS.

The problem in this case is to find the position of the load causing a maximum influence-*quantity*. This will usually have to be done by *trial*, by finding Y for various positions of the system and taking the greatest value found. The system of loads may be laid off on a slip of paper, and this latter moved around along the influence-line into the different positions that the load may assume. If we lay off Y along one of the loads for the various positions of the system and join the ends of these ordinates, we obtain a line which we may call the secondary influence-line; if the influence-line is composed of right lines, the secondary one will be a straight line as long as the loads in the several parts of the influence-line, which are straight, remain unchanged; (since $y_1 = x_1 \tan \alpha_1$, $y_2 = x_2 \tan \alpha$, $\therefore Y = \tan \alpha \, \Sigma Px = x_0 \tan \alpha \, \Sigma P_1$ x_0 being distance of resultant of loads in straight part of influence-line from the intersection of the axis and this part). The secondary influence-line will, therefore, be a broken line, the corners corresponding to that position of the system of loads in which one of them crosses a corner of the original influence-line. It is easily seen that the corner of the secondary influence-line will be re-entrant or salient, according as the angle of the influence-line crossed by a load is re-entrant or salient, the ends being considered as re-entrant angles.

The maximum of the influence-quantity must be at a salient angle, ∴ for a maximum of the influence-quantity a load must lie at a salient angle of the influence-line (Fig. 9). The maximum may happen to correspond to a side of the secondary influence-line; in this case, the position of the system of loads may be changed within certain limits without affecting the value of Y.

MAXIMUM FOR TRIANGULAR INFLUENCE-FIGURE.

Let $A\,B\,C^1$ (Fig. 10) be the influence-figure, R_1 the resultant of the forces acting in $A\,C_1$, R_2 the resultant of those in $B\,C_1$, y_1 the ordinate of R_1, y_2 the ordinate of R_2; $Y = R_1\,y_1 + R_2\,y_2$. If we move the system of loads to the right, y_1 is increased by $\delta \tan \alpha_1$ and y_2 diminished by $\delta \tan \alpha_2$, δ being the distance moved, ∴ $\Delta\, Y_1$ the change in $Y = \delta\,(R_1 \tan \alpha_1 - R_2 \tan \alpha_2)$; if $R_1 \tan \alpha_1 > R_2 \tan \alpha_2$, $\Delta\, Y$ is positive, and the system must be moved to the right to make Y a maximum; this causes $R_1 \tan \alpha_1$ to decrease and $R_2 \tan \alpha_2$ to increase, until finally $R_2 \tan \alpha_2 > R_1 \tan \alpha_1$, when the system must be moved back to the left, since $\Delta\, Y$ is negative and Y decreases, ∴ for a maximum of Y, $R_1 \tan \alpha_1$ must be as nearly equal as possible to $R_2 \tan \alpha_2$ or $\frac{R_1}{l_1}$ as nearly equal as possible to $\frac{R_2}{l_2}$. We must move the system towards the side having the lesser $\frac{R}{l}$, until the value of $\frac{R}{l}$ for this side becomes the greater, and then move it back so that a load acts at $C\,C^1$, as shown previously. It may happen that the condition $\frac{R_1}{l_1}$, as nearly equal as possible to $\frac{R_2}{l_2}$, is satisfied for various positions of the system, but it is evident that the heaviest loads must act at $C\,C^1$ to produce a maximum.

Example: Assume the influence-figure and system of

loads as shown in Fig. 11; if we place the system so that the first load acts in l_1, loads 2, 3, 4 and 5 act in l_2

FIG. 9.

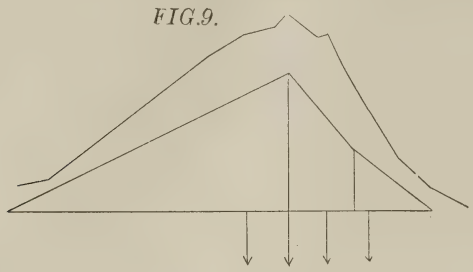


FIG. 10.

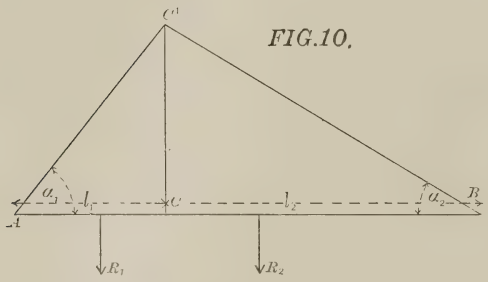


FIG. 11.

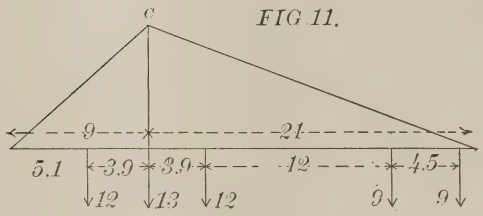
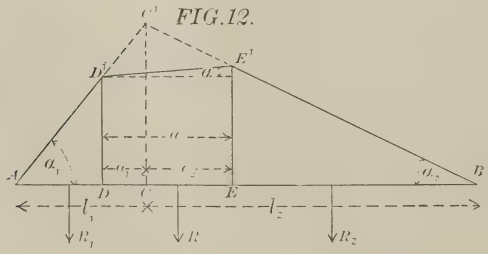


FIG. 12.



$\therefore \frac{R_1}{l_1} = \frac{12}{9}$ and $\frac{R_2}{l_2} = \frac{43}{21}$, $\therefore$ we must move it to the left; if loads 1 and 2 act in l_1, 4, 3 and 5 act in l_2, $\therefore \frac{R_1}{l_1} = \frac{25}{9}$ and $\frac{R_2}{l_2} = \frac{30}{21}$, $\therefore$ we must move the system to the right; for a maximum, the second load must accordingly act at C. If the altitude is one, Y for this position is $12 \frac{5.1}{9} + 13 \times 1 + 12 \frac{17.1}{21} + 9 \frac{5.1}{21} + 9 \frac{0.6}{21} = 32.02$.

MAXIMUM FOR QUADRILATERAL INFLUENCE-FIGURE.

Let $A D^1 E^1 B$ (Fig. 12) be the influence-figure, R_1, R and R_2 the resultants of the forces acting in $A D$, $D E$ and $E B$; if the system be moved δ to the right, $\Delta Y = \delta (R_1 \tan \alpha_1 + R \tan \alpha - R_2 \tan \alpha_2)$; if $C C^1 = h$, $D D^1 = h_1$, $E E^1 = h_2$, $h_1 = h \left(1 - \frac{a_1}{l_1}\right)$, $h_2 = h \left(1 - \frac{a_2}{l_2}\right)$, $\tan \alpha = \frac{h_2 - h_1}{a}$, $\tan \alpha_1 = \frac{h}{l_1}$, $\tan \alpha_2 = \frac{h}{l_2}$ $\therefore$

$$\Delta Y = \delta h \left[\frac{R_1}{l_1} + \frac{R}{a} \left(\frac{a_1}{l_1} - \frac{a_2}{l_2} \right) - \frac{R_2}{l_2} \right] \text{ or}$$

$$\Delta Y = \delta h \left(\frac{R_1 + R \frac{a_1}{a}}{l_1} - \frac{R_2 + R \frac{a_2}{a}}{l_2} \right)$$ $\therefore$ for a maximum of Y_1 we must have $\frac{R_1 + R \frac{a_1}{a}}{l_1}$ as nearly equal as possible to $\frac{R_2 + R \frac{a_2}{a}}{l_2}$ and a load will have to act either at $D D^1$ or $E E^1$.

Example: Let $A\,D^1\,E^1\,B$ be the influence-figure (13); assume the system of loads as in the previous example; if we place it so that loads 1 and 2 act in $D^1\,E^1$, and 3 and 4 in $E^1\,B$ (Fig. 13), $\dfrac{R_1 + R\dfrac{a_1}{a}}{l_1} = \dfrac{\frac{1}{3}(12 + 13)}{9} = 0.93$, $\dfrac{R_2 + R\dfrac{a_2}{a}}{l_2} = \dfrac{12 + 9 + \frac{2}{3}(12 + 13)}{21} = 1.79$, $\therefore$ the system must be moved to the left; if we place it so that 1, 2 and 3 act in $D^1\,E^1$, 4 in $E^1\,B$, $\dfrac{R_1 + R\dfrac{a_1}{a}}{l_1} = \dfrac{\frac{1}{3}(12 + 13 + 12}{9}$ $= 1.37$ and $\dfrac{R_2 + R\dfrac{a_2}{a}}{l_2} = \dfrac{9 + \frac{2}{3}(12 + 13 + 12)}{21} = 1.60$ $\therefore$ it must be moved still further to the left; if 1 acts in $A\,D^1$, 2 and 3 in $D^1\,E^1$, and 4 in $E^1\,B$, $\dfrac{R^1 + R\dfrac{a_1}{a}}{l_1} =$ $\dfrac{12 + \frac{1}{3}(13 + 12)}{9} = 2.26$ and $\dfrac{R_2 + R\dfrac{a_2}{a}}{l_2} = \dfrac{9 + \frac{2}{3}(13 + 12)}{21}$ $= 3.66$ $\therefore$ the system must be moved to the right, and load 1 must act at D^1.

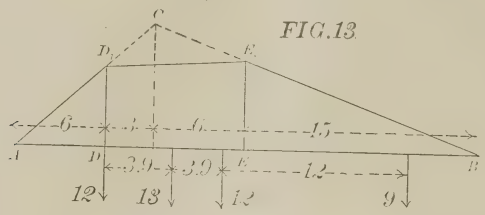
Since the two figures discussed are the influence-figures for the *moments*, the latter will be a maximum, when the loads act as just shown; when the load is uniformly distributed, the whole beam must be loaded; as the strains in the chords are directly proportional to the movements at the different sections, these positions of the load will give the maximum strains in the members of the upper and lower chords. $S^1 = \dfrac{M}{h}$, M being

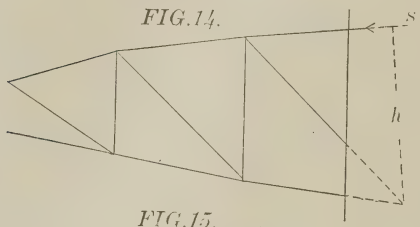
the moment for the center of moments, h the perpendicular distance from this point to the member whose strain is to be found, and S the strain in this member (Fig. 14).

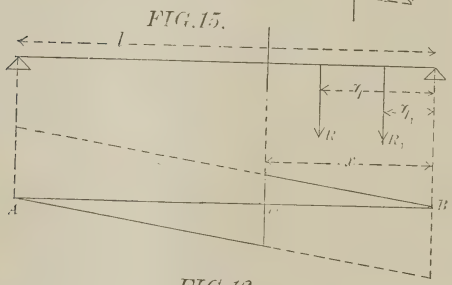
MAXIMUM SHEARING FORCE FOR LOAD ACTING DIRECTLY.

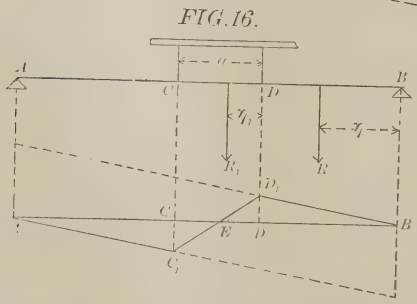
The influence figure is shown in Fig. 15. Let the first load of the system act just to the right of C; S_1 the shearing force is $R \frac{\eta}{l}$, L being the resultant of all the forces acting, η the distance of R from the right abutment, and l the length of the beam. If the system be moved so that the second load acts just to the right of C_1, and if new loads having a resultant, R_1, at a distance, η_1, from the right abutment, roll upon the beam, $S_1 = \frac{R(\eta + \delta) + R_1 \eta_1 - P_1 l}{l}$, δ being the distance moved, and P_1 the first load of the system. If $S_1 > S$, $R\delta + R_1 \eta_1 - P_1 l > 0$, or $P_1 l < R\delta + R_1 \eta_1$; when the heaviest loads with the least distance between them are in front, $\frac{P_1}{\delta} > \frac{R + R_1}{l - x + \delta}$, x being the distance of the section from the right abutment; since $\eta_1 < \delta$ and $l - x + \delta < l$, $P_1 l > R\delta + R_1 \eta_1$, therefore, in this case, the first load must act at C for maximum S; if light loads are at the head, the second load may have to act at C for a maximum S. In the same manner, we find that if the conditions $P_1 l < R\delta + R_1 \eta_1$ and $P_2 l < R\delta_1 + R_1 \delta_1 + R_2 \eta_2$ are satisfied (P_2 being the second load, δ_1 its distance from the third, R_2 the resultant of the new loads that roll upon the beam when the system is moved δ_1, η_2 the distance of R_2 from the right abutment), the third load must act at C to make S a maximum. For the negative maximum of S_1 the load

must act from C to the left abutment, and we have simply to change "right" to "left" in the above discussion.









If the load is uniformly distributed, it must extend from C to B for a positive maximum, and from C to A for the negative maximum or the minimum.

MAXIMUM SHEARING FORCE FOR LOAD ACTING INDIRECTLY.

The influence-figure in this case is shown in Fig. 16. If R is the resultant of all the loads acting on the beam, η its distance from B, R_1 the resultant of the loads in CD, η_1 its distance from D, S the shearing force is $R\frac{\eta}{l} - R_1\frac{\eta_1}{a}$, a being CD; if the system be moved δ to the right, η and η_1 are diminished by δ, if S_1 be the shearing force for this position, $S_1 - S = \left(\frac{R_1}{a} - \frac{R}{l}\right)\delta$ therefore, for a maximum of S, $\frac{R_1}{a}$ must be as nearly equal as possible to $\frac{R}{l}$, or the load per unit on AB must be as nearly equal as possible to the load per unit on CD, the system extending from C to B; one load must act at either C or D.

If the load be uniformly distributed, it must extend from E to B to produce a maximum in the value of S, and from E to A to produce a minimum. ED may be found as follows: In the similar triangles EBD^1 and EAC^1, $EB : ED :: AE : EC$, or if $ED = z$, $DB = x$, and $AB = l$, $x + z : z :: l - x_1 - z : a - z$, therefore, $z = \frac{a x_1}{l - a}$.

In trusses with horizontal chords, the strains in the verticals and diagonals are proportional to the shearing force; therefore, the load producing a maximum shearing force produces a maximum strain in these members. If T be the strain in any brace, α the angle that it makes with the vertical, $T = S \sec \alpha$; therefore, if we substitute the value of maximum S, we obtain the maximum value of T, and by substituting the minimum of S we obtain T minimum, and from this we may find the bays in which counterbraces are required.

In trusses with curved upper or lower chords, or with both chords curved, T will not be a maximum when S is. This is readily seen if we take the condition for equilibrium: $S - C \sin \beta - C_1 \sin \gamma = T \cos \alpha$ (Fig. 17); T does not become a maximum for $S =$ maximum, but for

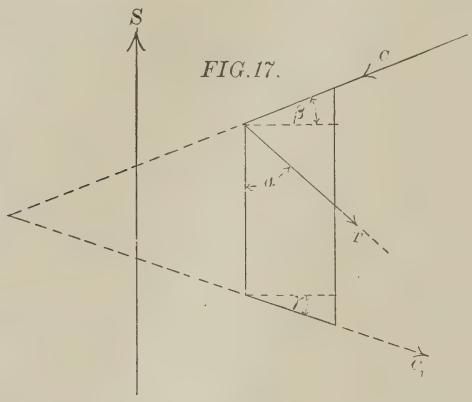


FIG. 17.

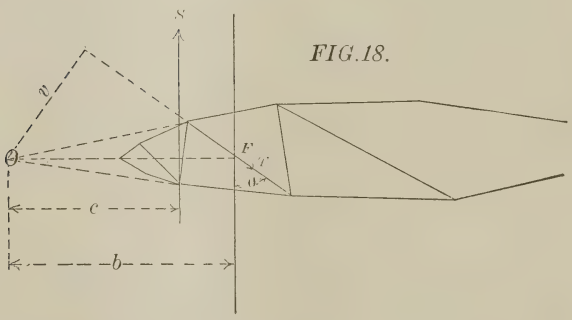
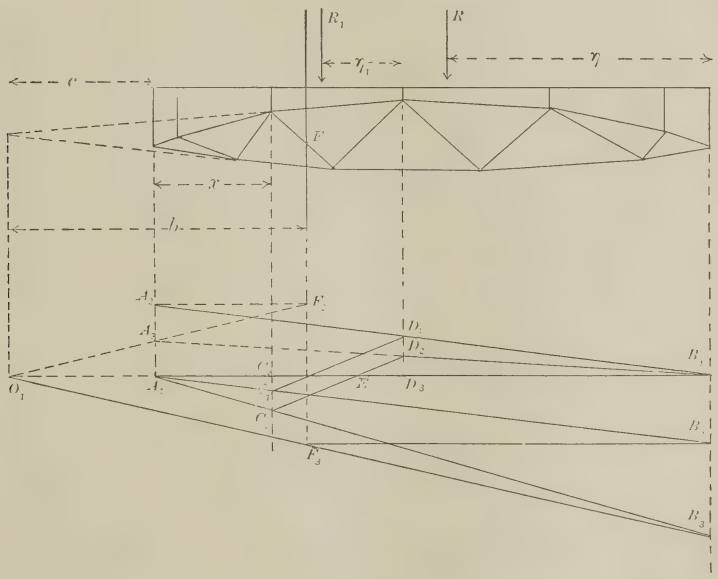


FIG. 18.

$(S - C \sin \beta - C_1 \sin \gamma) =$ maximum, in which S, C and C_1 are all variables, depending on the position of the load. If we take moments around the intersection of the chords, $Tv = Sc$ (Fig. 18); $v = b \cos \alpha$, therefore $T = S \frac{c}{b} \sec \alpha$, therefore T becomes a maximum for $S \frac{c}{b}$ $=$ maximum. For any position of a load to the right

of the bay in which the section is situated, c is the distance between O and the left abutment, and b the distance between O and F, since the only external force is the reaction on the left. For any position of a load to the left of this bay, c is the distance between O and the right abutment, and b the distance between O and F, as before; therefore, $\frac{c}{b}$ is a constant in both cases, but greater in the second case than in the first. If, now, from the influence-line for S on both sides of the bay we

FIG. 19.



construct the influence-line for $S\frac{c}{b}$, this will give the position of the load causing T to become a maximum. This may be done as follows (Fig. 19): Let $B_1 D_1 C_1 A_1$ be the influence-line for the section through F for the

shearing force, the load being assumed to act on the upper chord. Draw the horizontal line $A_2 F_2$, then $F_2 O_1$ and $A_3 B_1$; $B_1 D_2$ is the influence-line for $S \frac{c}{b}$ for loads in $B_1 D_3$; draw the horizontal line $B_2 F_3$; then, $O_1 F_3 B_3$ and $A_1 B_3$; $A_1 C_2$ is the influence-line for loads in $A_1 C_3$; the line between C_2 and D_2 is straight. The influence-line need not be constructed for S, but $A_1 A_2$ and $B_1 B_2$ may be laid off equal to the load for which this line is to be drawn, and the other operations for finding the influence-line for $S \frac{c}{b}$ performed as above. The position of a system of concentrated loads making $S \frac{c}{b}$ a maximum may be found thus: Let R be the resultant of all the loads acting on the beam, η its distance from B_1, R_1 the resultant of the loads in $C_3 D_3$ in which the section is situated, η_1 its distance from D_3, c the distance $O_1 A_1$, x the distance $A_1 C_3$, b the distance $O_1 F_3$; the external forces acting to the left of the section are $R \frac{\eta}{l}$ at the abutment A, and the downward force $R_1 \frac{\eta_1}{a}$ at C_3. The strain in the number due to the former is $T_R = R \frac{\eta}{l} \frac{c}{b}$ sec α; that due to the latter is $T_R = - R_1 \frac{\eta_1}{a} \frac{(c + x)}{b}$ sec α; therefore the total strain $= T_{R_1} + T_R = T = \left(\frac{R\eta}{l} c - \frac{R_1 \eta_1}{a} (c + x) \right) \frac{\sec \alpha}{b}$. If we move the system of loads δ to the right, η and η_1 are diminished by this amount, therefore ΔT the change in T caused by this $= \left(\frac{R_1 (c + x)}{a} - \frac{Rc}{l} \right) \frac{\delta}{b}$ sec α; for a maximum of

T, and therefore of $S \frac{c}{b}$; $\frac{R_1 (c + x)}{a}$ must be as nearly equal as possible to $\frac{Rc}{l}$, or $\frac{R_1 (c + x)}{ac}$ to $\frac{R}{l}$, and a load must act at D_3 or C_3. If $S \frac{c}{b}$ maximum is found for this position of the load, T maximum $= \left(S \frac{c}{b} \text{ maximum} \right) \sec \alpha$; for the negative maximum, the distance $A_1 E$ must be loaded so that $\frac{R_1 (c_1 + x_1)}{ac}$ is as nearly equal as possible to $\frac{R}{l}$, c being $O_1 B$; and x_1 the distance $O_1 D_3$. This negative maximum shows in what bays counter-bracing is required.

If the load be uniformly distributed, it must extend from E to B_1 for the positive maximum, and from A_1 to E for the negative maximum of $S \frac{c}{b}$ and T; since $T = S \frac{c}{b} \sec \alpha$, the maximum of $\pm T =$ (the maximum of $\pm S \frac{c}{b} \Big) \sec a$. The multiplication of $S \frac{c}{b}$ by $\sec a$ may be performed graphically.

From the similar triangles $E D_3 D_2$ and $E C_3 C_2$, we have: $E D_3 : D_3 D_2 :: E C_3 : C_3 C_2$, or if the influence-line be drawn for P and $E D_3 = z$, $z : P \frac{c}{b} \frac{l - x - a}{l}$

$$:: a - z : P \frac{c + l}{b} \frac{x}{l} \therefore z = a \frac{l - x - a}{l \frac{c + x}{c} - a}.$$

TECHNICAL SOCIETY OF THE PACIFIC COAST.

SAN FRANCISCO, CALIFORNIA.

INSTITUTED APRIL, 1884.

PROCEEDINGS.

(VOLUME VIII. No. 2.

MINUTES OF MEETINGS.

REGULAR MEETING.

July 3d, 1891.

Called to order by President Richards.

The minutes of the last regular meeting were read and approved.

Election to membership:

Members—A. C. Paulsmeyer, mechanical engineer; Chas. H. Congdon, civil engineer; B. L. McCoy, county surveyor of Butte; O. C. Sanne, marine engineer; Lucien N. Sullivan, mechanical engineer.

Junior—Ernest McCullough, surveyor.

Associates—S. A. Sanderson, Chas. Floyd Barcus.

The following names were proposed:

For members—A. J. Brownlie, civil engineer of Portland, Or., proposed by Otto von Geldern, Geo. F. Schild and John B. Pitchford; Frederick T. Newbery, civil engineer, proposed by John Richards, Geo. F. Schild and Otto von Geldern; Emil Newman, civil engineer, proposed by Lewis Tasheira, L. A. Corneille and Otto von Geldern.

For Honorary Member—Adolph Sutro, of San Francisco, proposed by Luther Wagoner, G. W. Percy and John Richards.

The resolutions offered by Mr. Wagoner at the last regular meeting, regarding certain changes in the order of business as prescribed by the By-laws, was upon motion adopted.

President Richards appointed Vice-President Wagoner to the chair and read a continuation of his paper entitled, "Abrasive Cutting in the Mechanic Arts." Upon motion the discussion of this interesting subject was postponed until the next meeting.

Mr. Marsden Manson then read a paper on "Physical and Geological Traces of Permanent Cyclone Belts," which led to an interesting discussion, during which a statement was read from Professor Le Conte, and remarks were offered by Lieutenant John P. Finley, of the U. S. Weather Bureau.

Meeting adjourned.

REGULAR MEETING.

August 7th, 1891.

Called to order by President Richards.

The minutes of the last regular meeting were read and approved.

Election to membership:

Members—A. J. Brownlie, civil engineer, Frederick T. Newberry, civil engineer, Emil Newman, civil engineer.

Honorary Member—Adolph Sutro.

The following names were proposed:

For Member—J. M. Finch, mechanical engineer, proposed by Geo. F. Schild, E. J. Shrader and H. C. Behr.

For Associates—Jared L. Rathbone, proposed by Otto Von Geldern, Hubert Vischer, and Geo. F. Schild; F. E. Leppien, proposed by Otto von Geldern, Hubert Vischer and Geo. F. Schild.

Mr. Hubert Vischer spoke at length on the "USE OF THE FIGURE NINE" as a check in arithmetical calculations, referring to a number of cases in order to illustrate the valuable aid of such a check to the computer.

Mr. John Richards then briefly addressed the Society on "NATURAL STANDARDS," calling attention to the various means employed for evolving a natural measure, specifying the metre, the length of the pendulum beating certain measures of time, and various other methods for obtaining a unit of length that could always be referred back to some existence in nature.

The Secretary called attention to a resolution offered May 1st, by which it was attempted to reduce the admission fee and the dues of the associate member. Mr. Vischer proposed to amend this resolution so as to read: that the admission fee remain $5.00, as heretofore, but that the dues be reduced from $1.00 to 50 cents per month; and that the same rates be applied to the junior member, whether resident or non-resident. The amendment was accepted and the resolution was then carried as amended.

Meeting adjourned.

REGULAR MEETING.

September 4th, 1891.

Called to order by President John Richards.

The minutes of the last regular meeting were read and approved.

Elections to membership:

Member—J. M. Finch, mechanical engineer.

Associates—Jared L. Rathbone, F. E. Leppien.

The following names were proposed:

For members—Howard C. Holmes, civil engineer, proposed by Hubert Vischer, S. Harrison Smith and Otto von Geldern; Randell Hunt, civil engineer, proposed by Hubert Vischer, Marsden Manson and S. Harrison Smith; James M. Gleaves, civil engineer, of Redding, Cal., proposed by J. R. Mauran, J. C. Sala and Geo. F. Schild; Elbert P. Callender, civil engineer, of Knappton, Wash., proposed by Luther Wagoner, Hubert Vischer and S. Harrison Smith; James T. Taylor, civil engineer, of Pomona, proposed by Jas. D. Schuyler, P. J. Flynn and Otto von Geldern; Alfred Solano, civil engineer, of Los Angeles, proposed by P. J. Flynn, Burr Bassell and Otto von Geldern.

The Secretary read the following letter received from the Governor of the State:

"EXECUTIVE DEPARTMENT,
Sacramento, Cal., Aug. 5th, 1891.

To Otto von Geldern, Secretary Tech. Soc.,
San Francisco.

Dear Sir:—I am in receipt of a letter from A. T. Herrmann, Esq., of San Jose, in answer to one from this office in regard to the Convention to be held at Salt

Lake City for the purpose of discussing matters connected with irrigation. Mr. Herrmann suggests that an inquiry be submitted to the Technical Society in time for its meeting on Friday, August 7th, that the members may furnish any information they may have upon the subject. My understanding of the matter is that most of the discussions will be upon the United States ceding to each State and Territory the arid public lands within its borders, and that irrigation matters should be subject to State legislation. You, as well as other members of your Society, are quite well aware that there is quite a difference of opinion on this subject, and as far as I can ascertain the general drift of the sentiment in this State is against such cession. However, in accordance with Mr. Herrmann's suggestion, the question is submitted to you for whatever action you may take in the matter.

Yours, very truly,

(Signed) M. R. Higgins,

Private Sec."

Mr. Hubert Vischer moved that in order to show our interest in the matter, a committee be appointed fully empowered to act; which committee shall communicate with the Irrigation Congress and notify the Governor of the State of the action of the Technical Society.

The motion was carried, whereupon the President appointed Messrs. Hubert Vischer, A. T. Herrmann and C. E. Grunsky, with instructions to proceed at once.

This committee subsequently drew up the following letter to the Irrigation Congress, copies of which were furnished Governor Markham and the Society's representative, Mr. Wm. Ham. Hall.

"TECHNICAL SOCIETY OF THE PACIFIC COAST.
San Francisco Sept. 12th, 1891.

To the President and Delegates of the Irrigation Congress, Salt Lake City, Utah.

GENTLEMEN—An expression of opinion by the Technical Society of the Pacific Coast, regarding the policy of a cession of the arid lands by Congress to the several States and Territories having been invited by Mr. H. H. Markham, Governor of the State of California, we have been appointed by that Society as a committee to express the prevailing sentiment.

Our Society views with fitting interest the question proposed for discussion at Salt Lake City, but is not prepared to express a definite opinion as to whether the reclamation of the arid public lands can be best effected through the agency of the individual States or under the direct supervision of the general government of the United States; but we do hereby desire to give expression to our conviction that no transfer of arid lands to the several States and Territories should be made except after due investigation, and after a study of the conditions and the requirements of the lands susceptible of reclamation; that prior to actual cession, comprehensive plans for outlining the general scope and character of the required irrigation works, and the amount of water available and allotted to each natural district be prepared, and that no cession of any lands shall be made, except under proper guarantee that actual reclamation of the lands shall be the essential condition of the transfer, and the vesting of final title in private hands.

It not only seems necessary to us that the available water supply be apportioned to the arid land regions to which it naturally belongs, but that no cession of arid lands to any State should be made, except when such

arid lands are included within the boundaries of some natural district for which irrigation works have been planned by the proper U. S. department, and with the reservation that the works thus planned for reclamation be carried out subject to the approval of the proper U. S. authorities, and that when irrigation works are contemplated, a reasonable interest on the capital required to construct them be guaranteed by each State or by Congress, and that, finally, no sale of any arid land reclaimed under the terms of any law passed for the purpose of ceding the arid lands to the several States and Territories should be authorized, except at prices at least sufficient to cover the cost of the works required to effect reclamation.

It seems self-evident that if lands are granted to the several States for reclamation, the grant should be subject to such restrictions as will require uniform procedure in the several States when reclamation is to be accomplished.

Our fellow member, Mr. Wm. Ham. Hall, who will attend the Congress as a delegate from California, is requested to present our views, without prejudice to his personal actions or opinions as a delegate.

Respectfully submitted,

HUBERT VISCHER,
A. T. HERRMANN,
C. E. GRUNSKY,
Committee."

Mr. Louis Falkenau read a paper on the Occurrence of the Onyx (so called) in California, Arizona, Mexico and elsewhere, pointing out the manifold uses of this material in the decorative arts.* A number of beautiful

* This paper will be published in a subsequent bulletin.

specimens were exhibited, illustrating the manner of working the stone and the high degree of polish it may be made to take.

The President announced the probable visit of the American Society of Mechanical Engineers to California, at the time of its next spring meeting. He stated that some correspondence had taken place on the subject with Professor J. E. Sweet, of Syracuse, N. Y., and that it would be necessary to obtain the views of the Society in this matter.

After some discussion it was agreed to appoint a committee of sixteen members, to take preliminary steps in the way of ascertaining the opinion of the business community, in order to determine whether, if such an invitation were extended, it would be possible to carry out the plan successfully of entertaining the Society.

The following gentlemen were appointed on such committee:

Adolph Sutro, I. M. Scott, Geo. W. Dickie, W. R. Eckart, James Spiers, R. S. Moore, E. J. Molera, P. Noble, Byron Jackson, J. D. Isaacs, Charles G. Yale, Carl A. Stetefeldt, Robert Hinchliffe, Marsden Manson, A. P. Brayton and Otto von Geldern.

Upon motion, the meeting was adjourned until Monday evening, September 14th.

ADJOURNED MEETING.

Sept. 14th, 1891.

Called to order by President Richards.

Mr. Marsden Manson addressed the Society at length, explaining an original theory to account for the glacial period of our globe. The general principle announced

was, that while the climates of the earth passed from the control of earth heat to that of solar heat, there must have been an intervening period between those two epochs, during which sufficient energy was retained in the oceans, by reason of the high specific heat of water, to maintain a dense cloud shield which must have shut out the influences of solar heat. This interval Mr. Manson announces as the great ice age in the earth's history.

The paper was discussed by a number of members present, the President calling attention to the fact that the subject had been most remarkably handled, that it had been dealt with in the manner of the engineer by applying measures and gauges to the physical forces involved.

Further remarks were made by Colonel Mendell, Professor Soulé and Messrs. Vischer, Grunsky and Van der Naillen.

After passing a vote of thanks for the author the meeting adjourned.

SATURDAY, Sept. 26th, 1891.

Upon an invitation cordially extended by the firm of Ransome & Cushing to the Technical Society, to inspect the Museum Building and the Girls' Dormitory of the Leland Stanford, Jr., University, erected in concrete, about fifty members went in a body to Palo Alto, where they were shown these structures and the manner of erection.

Mr. E. L. Ransome escorted his guests through the building, explaining the method of his work and giving them an opportunity to examine every detail of the construction.

At 1 P. M. the Society was invited to a luncheon spread for the occasion, after which Mr. Geo. F. Allardt, acting President, addressed the Society and complimented the builders on their success in this particular branch of technology. Other speakers followed, all expressing their gratification to the hosts. The party returned to San Francisco on the evening train.

REGULAR MEETING.

October 2nd, 1891.

Called to order by Geo. F. Allardt, Chairman.

The minutes of the last regular meeting were read and approved.

Election of new members—Howard C. Holmes, civil engineer; Randell Hunt, civil engineer; James M. Gleaves, civil engineer; Elbert P. Callender, civil engineer; James T. Taylor, civil engineer; Alfred Solano, civil engineer.

The following names were proposed:

For Members—Frank P. McCray, civil engineer, San Diego, proposed by A. T. Herrmann, Chas. Herrmann and Otto von Geldern; Horace B. Gale, Professor of Mechanical Engineering Leland Stanford, Jr., University, proposed by John Richards, A. Schierholz and H. C. Behr; Henry S. Wood, civil engineer, proposed by Carl Uhlig, Otto von Geldern and Hubert Vischer; Fredk. Eaton, civil engineer, Los Angeles, proposed by A. Schierholz, H. C. Behr and L. Wagoner.

Mr. T. W. Morgan, City Engineer of Oakland, read a paper and exhibited a number of models to illustrate a method of purifying the noxious gases arising from sew-

ers.* The device consists of a receptacle attached to a man-hole, which is filled with charcoal, through which the gases are made to pass before escaping from the sewers into the streets. The properties of the charcoal as a disinfecting agent were discussed at length, Mr. Morgan stating that the results obtained in his practice had proven highly satisfactory and were worthy of a careful examination.

A general discussion of the subject then followed.

Mr. C. E. Grunsky read a paper in which he reviewed and briefly discussed Mr. Marsden Manson's theory of the Cause of the Glacial Period.

Upon motion, all further debate on the subject was postponed until the next regular meeting on account of the lateness of the hour.

The Secretary was instructed to convey the thanks of the Society to Messrs. Ransome & Cushing for the enjoyable trip arranged by them to the Leland Stanford, Jr., University, for the purpose of inspecting the two prominent concrete structures built there by that firm. It was further moved that Mr. E. L. Ransome be invited to prepare a technical paper on the subject and present it at some future meeting.

Adjourned.

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*This paper will be published in a subsequent issue of the Transactions.

PUBLIC MEETING.

October 21st, 1891.

Held in the main hall of the Academy of Sciences, beginning at 8 P. M., President John Richards presiding.

The meeting had been advertised in the local newspapers and the attendance was quite a large one.

Mr. Irving M. Scott addressed the audience on observations made by him on all sorts of technical subjects, while on a recent tour abroad.

He referred to shipbuilding; the making and bending of armor plate; the facilities of European dockyards; the electric apparatuses as applied in England and Germany; and the great progress of similar work in the United States.

His address proved to be a most interesting one to the audience, his popular way of explaining the subject and expressing his views, made the technical features intelligible to all.

At the end of his discourse he was warmly applauded.

REGULAR MEETING.

November 6th, 1891.

Called to order by President John Richards.

The minutes of the last regular meeting were read and approved.

Election of new members:

Frank P. McCray, civil engineer; Professor Horace B. Gale; Henry S. Wood, civil engineer; Fredk. Eaton, civil engineer.

The following names were proposed:

For Members—Geo. B. Birrell, mechanical engineer, proposed by F. Orton, H. C. Behr and John Richards; Alex. O. Brodie, civil engineer, of Prescott, Ariz., proposed by Otto von Geldern, Geo. F. Schild and H. C. Behr; Geo. E. Dow, mechanical engineer, proposed by John Richards, Chas. G. Yale and H. C. Behr; David E. Hughes, civil engineer, of Irvington, Cal., proposed by F. Gottfried, Geo. F. Schild and Otto von Geldern; B. T. Lacy, mechanical engineer, proposed by F. Gottfried, H. C. Behr and John Richards; Edward A. Rix, mechanical engineer, proposed by F. Orton, H. C. Behr and Otto von Geldern; T. M. Shaw, civil engineer, of San Diego, Cal., proposed by Chalmers Scott, Jas. D. Schuyler and Adolph Lietz; J. C. Stanton, surveyor, of Rio Vista, Cal., proposed by Otto von Geldern, Geo. F. Schild and H. C. Behr; Hadwen Swain, mechanical engineer, proposed by John Richards, H. C. Behr and Otto von Geldern.

The President explained in a few words the action taken by the Technical Society in the matter of a proposed visit of the American Society of Mechanical Engineers to this State. A committee had been selected, and all further action is now left entirely in the hands of this committee, which consists principally of prominent business men of San Francisco.

Mr. Geo. W. Dickie having been called to the chair, the President read a paper prepared by himself, entitled "The Retired Life of James Watt, and his Workshop at Heathfield Hall."

Messrs. H. C. Behr and H. Kower were appointed tellers to open and count the ballots for the election of new members, with instructions to perform this duty on

all occasions *before* the meeting is duly opened for the transaction of regular business.

Mr. Marsden Manson read several letters received by him, referring to his paper on "The Cause of the Glacial Period."

A lengthy discussion of the subject followed in which Dr. Clark, Mr. Dickie, and several other prominent members took part.

General remarks were made by Professor Gale and Naval Constructor Stahl, the latter mentioning a system of intercommunication and discussion in vogue in the American Society of Mechanical Engineers. Topical questions of a technical character are asked by any member feeling so inclined; these questions are printed and submitted to all members of the Society for discussion and reply. At a subsequent meeting these questions are brought up and discussed.

It was suggested that this method be tried in the Technical Society, and that the Secretary have printed notices sent to all members, inviting them to submit topical questions for general discussion. This was finally ordered and the Secretary instructed to proceed in this matter.

Adjourned.

REGULAR MEETING.

December 4th, 1891.

Called to order by President Richards.

The minutes of the last regular meeting were read and approved.

Election of new members—Geo. B. Birrell, mechanical engineer, Alex. O. Brodie, civil engineer, Geo. E.

Dow, mechanical engineer, David E. Hughes, civil engineer, B. T. Lacy, mechanical engineer, Edward A. Rix, mechanical engineer, T. M. Shaw, civil engineer, J. C. Stanton, Surveyor, Hadwen Swain, mechanical engineer.

The following names were proposed:

For members—William C. Alberger, civil engineer, proposed by Geo. F. Allardt, Otto von Geldern and Geo. F. Schild; R. B. Elder, electrician, proposed by Hubert Vischer, H. C. Behr and John Richards; Frederick G. Hesse, Professor Mechanical Engineering, University of California, proposed by Hermann Kower, H. C. Behr and John Richards.

For Associate Member—Chas. A. C. Duisenberg, merchant, proposed by Hubert Vischer, H. C. Behr and Otto von Geldern.

The election of a nominating committee to propose names for officers and directors of the Technical Society for the ensuing year being in order, the following members were placed in nomination, the Secretary casting the vote and the chair announcing the result: L. J. Le Conte, Geo. F. Allardt, Hubert Vischer, Jos. C. Sala, F. Gottfried.

The following topical questions having been submitted to the Society, the Secretary proceeded to read them in their order and the chair declared them open for discussion:

1. How far is the storing or impounding of water practicable in California, and is it commercially practicable at all, except on nearly level areas?

2. How can we account for the fact that machine work in San Francisco is, with few exceptions, not

made to the national or any other standard for dimensions?

3. What would be the effect on the Pacific Coast of adopting metrical metrology in all branches of engineering and mechanical work made here?

4. What efficiency can be attained with a "Trompe" blowing apparatus, and have its laws been the subject of investigation?

After some consideration of the subjects involved, it was finally ordered that the second question be chosen. Mr. Richards began the discussion by making some general statements, referring particularly to the annoyance caused by not having some system in the measurements of our mechanical work.

Mr. Vischer called for an explanation of the existing facts, and Mr. Dickie proceeded to explain the usage in general practice here and the manifold systems of measure applied, whereupon Messrs. Behr, Swain, d'Erlach and Dow related their personal experience in this matter.

Mr. Wood suggested to publish a circular embodying the points discussed, and to distribute it among those directly interested, in order to arrive at an expression of opinion as to the advisability of adopting some uniform standard of measure in machine work.

The discussion of this topic led to a consideration of the third question, which was debated for some time by Messrs. Vischer, Kower, Dickie and others.

Meeting adjourned.

Otto von Geldern,
Secretary.

TECHNICAL SOCIETY OF THE PACIFIC COAST.

SAN FRANCISCO, CALIFORNIA.

INSTITUTED APRIL, 1884.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the statements and opinions advanced in any of its contributed publications.

(VOLUME VIII. No. 3.)

ONYX ON THE PACIFIC COAST.

BY PROFESSOR LOUIS FALKENAU, MEM. TECH. SOC.

[Read Sept. 4, 1891.]

The demand for material adapted to the interior decoration of buildings is steadily increasing, and for some time past variegated marble and the so-called onyx have been extensively used, as they are more easily cut and polished than other stones, and are otherwise preferable to many of the materials at our disposal.

Onyx proper is a species of quartz of great hardness, and occurs in small fragments, or nodules, while the so-called onyx of which this paper treats is mainly calcium carbonate, mostly in the modification called aragonite, and occurs in large masses. Its hardness is from 3½ to 4, its specific gravity from 2½ to 4, and it is easily cut into slabs and polished.

Onyx has been found in several localities of our State, but with a few exceptions, in small deposits, that do not yield large and perfect slabs. Large deposits have been found in Arizona, and new finds are constantly reported from all parts of the United States. Mexico has many fine deposits of onyx, most of which is used for clocks, table tops and small ornaments. The specimens of Mexican onyx, which I have here, are from La Sorpresa and La Mesa Mines, Tehuacan Pueblo, of which I have received the following description by the owners:

The deposits of onyx are found running through hills measuring about four miles across, at an angle of about 45 degrees, in layers of from 4 to 15 inches in thickness, separated from each other by parallel layers of clay, gravel and country rock. The deposits reappear on the other side of the cañon, running into the opposite hills at about the same angle.

The Sorpresa onyx is mostly white and green. The La Mesa, variegated. The first is near the bottom of the hills, the latter above it; a hard, red country rock separates the two mines. No marble, and no calcite crystals have thus far been found there. The deposits have been worked for three or four years without the use of machinery. From 5,000 to 6,000 cubic feet of onyx have been shipped to Paris, London and New York at a price of about $10 per cubic foot. The shipping port is Vera Cruz, which is reached in one day by railroad.

As the croppings of these deposits have been traced for five miles along the hillsides, and extend from the bottom of the hill to the top, the amount of available material is very great. The largest slabs obtained were 12 feet long, 8 feet wide and 5 feet in thickness.

In our State the deposits of Suisun, and of San Luis Obispo, have for several years past been worked by Messrs. J. & F. Kesseler, of this City, who have kindly furnished me these specimens and the following description of the San Luis Obispo quarry:

To Prof. Louis Falkenau.—Sir: According to promise, we send you a short statement regarding our onyx mine in San Luis Obispo County, Cal. The mine is situated about thirty miles from San Luis Obispo, and about twenty miles from Pismo Beach. It lays in the hills between Huasno Creek and Arroyo Creek, about sixteen miles from Arroyo Grande, a station of the narrow gauge railroad. The ledge stands nearly perpendicular on the side of a hill. The earth and stone in front of the ledge have been removed to the depth of about forty or fifty feet for a distance of eighty feet along the ledge, which is sixteen feet wide on the top and gets thicker going down.

The croppings show themselves from three to four hundred feet along the ledge, and again about half a mile to the northwest. The blocks stand all on their edges, and are from two to three feet, from eight to twelve feet, and some from fifteen to twenty feet long, and from six inches to eighteen inches thick.

Along the ledge there are also several valuable mineral springs.

The onyx has beautiful colors—red, green, sky-blue, rose color, and a lovely golden yellow. The rich colors run in charming and graceful transition from one shade to another. Men who have worked and used onyx extensively declare it to be the finest onyx known. It has solidity, large sizes, beautiful colors, and an endless variety of tints. It is within easy reach of San Francisco, whence it may be shipped to all parts of the world.

Surrounding the mines and springs are nine hundred and twenty-nine acres of land, which form part of the property; they have plenty of timber and running water, and would form a beautiful park for the springs. Very respectfully,

San Francisco, March, 1891. J. & F. KESSELER.

I have no knowledge of other deposits in California having been worked to any extent. The Arizona deposits, discovered in August, 1889, which I visited in September, 1890, are located in Yavapai County, about 28 miles southwest from Prescott. The onyx is found in a group of low rolling hills. Eleven claims of 600 × 1,500 feet cover the location. The bottom of the hills, and the beds of the creeks and gulches surrounding them show strata of conglomerate, formed of fragments of onyx mixed with other rock and cemented by lime carbonate. Above these the onyx crops out boldly in well-defined strata of from 12 to 20 feet in height, extending into the hills almost horizontally, with a slight dip toward the center.

The tops of the hills show indications of onyx, and several shafts sunk at a considerable distance from the hillsides show solid masses of onyx immediately below the surface. At the time of my visit, only about 1,800 square feet of the ground had been explored by cuts and shafts. At a very conservative estimate, I would say that there were 1,440,000 cubic feet, equal to 144,000 tons of onyx then available. Should, as is very probable, the balance of the still undeveloped croppings, prove to represent strata of equal dimensions to those already opened, the available supply would be practically inexhaustible. Large blocks, some 7 × 4 feet and 18 inches in thickness, had been separated from the mass by blasting, and from such blocks most of the samples I have here were broken by a sledge hammer. That the material stood such treatment as well as it did speaks highly for it.

The many varieties found in this deposit differ very much in color and density (8 to 10 cubit feet per ton.) Analysis showed the

presence of iron, manganese, strontia and magnesia, and it is to the iron and manganese the different tints are due.

Several tons of the onyx were taken to Colton to be cut and polished. The small slabs I have here are samples I brought from there.

Lately a new location has been found near Phœnix, Arizona, which is said to produce onyx of good quality and in great abundance. The cost of onyx varies from $5 to $10 per cubic foot, and over. To what extent it is used may be inferred from the following amounts expended on it: In Vanderbilt's residence, Newport, $250,000; C. P. Huntington's residence, New York, $100,000; Equitable Building, New York, $75,000; Auditorium Hotel, Chicago, $60,000; Imperial Hotel, New York, $500,000; Grand Union Hotel, New York, $25,000.

At the time the foregoing paper was read there were exhibited about forty specimens of onyx having polished surfaces and presenting almost every shade of color, and showing the laminations which indicated the manner of its formation by desposition.

REGULAR MEETING, JANUARY 7th, 1892.

PROCEEDINGS.

MINUTES.

Held in the main hall of the Academy of Sciences, and called to order by the President at 8:30 P. M.

The reading of the minutes of the last regular meeting was ordered to be dispensed with.

The following new members, having been balloted for, were declared elected:

Professor F. G. Hesse.....University of California.
Wm. C. Alberger, civil engineer.....San Francisco.
R. B. Elder, electrician ..... "
Chas. A. C. Duisenberg, merchant, Associate..... "

The following names were proposed for membership and referred to the Board of Directors:

For members:

Frank H. Olmsted, civil engineer, of Riverside, Cal., proposed by Burr Bassell, P. J. Flynn and Otto von Geldern.

L. C. Russel, mechanical engineer, San Francisco; proposed by C. A. Stetefeldt, F. Orton and John Richards.

Theodore Wetzel, Jr., mining superintendent, North Bloomfield, Cal.; proposed by A. d'Erlach, Geo. F. Schild and Otto von Geldern.

For juniors:

Geo. P. Cramer, surveyor, Seattle, Wash.; proposed by J. P. F. Kuhlmann, Luther Wagoner and Hubert Vischer.

J. F. Morrow, surveyor, San Francisco; proposed by Hurbert Vischer, Luther Wagoner and Otto von Geldern.

The Nominating Committee made the following report, proposing names for officers and directors of the Society for the ensuing year:

SAN FRANCISCO, January 4th, 1892.

To the Members of the Technical Society of the Pacific Coast:

GENTLEMEN: Your Nominating Committee, selected to propose the names of candidates for election of officers and directors of the Society for the year 1892, herewith submits a report, and begs to propose the names of the following gentlemen:

President, John Richards. Vice-President, Luther Wagoner.
Treasurer, Geo. F. Schild. Secretary, Otto von Geldern.

DIRECTORS:

H. C. Behr. Geo. W. Dickie. W. R. Eckart.
C. E. Grunsky. A. Schierholz.

Your committee calls attention to the efficient management of the Society, and the progress made during the past year, and rejoices in having succeeded in so great a measure in inducing the same members to express their willingness to serve during the coming year.

Respectfully submitted,

L. J. LE CONTE,
GEO. F. ALLARDT,
HUBERT VISCHER,
J. C. SALA,
F. GOTTFRIED.
Nominating Committee.

The President then introduced Mr. Geo. W. Dickie to the audience, who proceeded to address the Society on the "Ocean Commerce of San Francisco," which was thereupon publicly discussed by those present.

(This interesting subject and discussion will be published in a subsequent bulletin.)

Adjourned.

OTTO VON GELDERN, *Secretary.*

ANNUAL MEETING, JANUARY 15th, 1892.

PROCEEDINGS.

MINUTES.

The annual meeting of the Society was held on Jan. 15, at the Society's rooms, in the Academy of Sciences Building.

The Ballots for officers for the current year were counted and the following officers were elected.

President, John Richards. Vice-President, Luther Wagoner.
Secretary, Otto von Geldern. Treasurer, Geo. F. Schild.

DIRECTORS:

H. C. Behr. Geo. W. Dickie. W. R. Eckart.
C. E. Grunsky. A. Schierholz.

After the ballot for officers had been declared the President presented and read the following address.

ANNUAL ADDRESS.

BY THE PRESIDENT, MR. JOHN RICHARDS.

(Read January 15th, 1892.)

In pursuance of a custom that is common in associations of this kind, and one that has much to recommend it, I will venture to occupy some of your time this evening with a kind of review of the various circumstances of the past year attending on our own Society, and the objects to which its energies are directed.

My first duty will be to acknowledge the honor conferred by the selection as your presiding officer for a third time. It has been a matter of circumstances rather than because of any claim or quali-

fication on my part, and is, for that reason, the more to be esteemed. It is unsafe to make promises for the future. For the present I can speak, and will say there is a stock of good resolutions covering such duties as I can perform.

The directors and their committees form the active governing element of the Society, shaping its policy and conducting its affairs, and for the coming year we will have in this capacity able and experienced members, who have consented to serve, in some cases, at a good deal of inconvenience to themselves.

During the past year some change has been made in the constitution and by-laws of the Society, not of a material kind, but relating mainly to procedure and the qualifications for membership. These changes are not of sufficient importance to require attention or comment at this time.

The reports of the Secretary and Treasurer show the condition of the Society, in respect to membership and finances, also show, or will call to mind the changes made in our environment, to so call it.

A good deal of money has been demanded, and a good deal spent, but, in all cases, with care and discretion. The present hall and its fittings, in which we have a proprietory interest; the very complete club room and connected offices, have been furnished and arranged during the past year, and, it is believed, will serve the requirements of the Society for many years to come, with only the expense of maintenance.

An important advantage during the past year has resulted from the Secretary's business permitting his presence here nearly all the time during business hours, and, I may add, also in a very efficient discharge of the duties pertaining to that office, which is really the main executive one in associations like this.

Turning now to retrospect, the Technical Society of the Pacific Coast has not been evolved from a small beginning and a few members, as is common in such cases, but it has, nevertheless, been obliged to follow the inexorable law of evolution, of which the main element is time. The Society was founded in 1884, and the roll signed at the time of organization, contained the names of 61 civil engineers; 30 mechanical engineers; 12 mining engineers; 11 architects; 6 chemists, and two patent attorneys; in all, 126 members.

This was an extraordinary beginning, not only in respect to the number of charter members, but also in the character and qualifications of those enrolled. It included most of the eminent engineers in the City, and as an assemblage of people engaged in technical pursuits, could not, perhaps, have been excelled among an equal population in any other part of the United States.

As a result of this, the first papers presented and read before the Society were remarkable. They speak for themselves, and I will digress here to say that the value of these papers was reciprocal, and their influence much wider than is commonly supposed.

A look through them recently, discloses the fact that, in most cases, the papers presented have aided and greatly promoted the interests of those who contributed them. The members who prepared these essays have become distinguished in the branches to which their papers related, perhaps they were so before, in most cases, but there is a fair inference that the time and pains invested in the work have been well returned.

It is to be hoped our new members will make a note of this. It is a road to professional success, and the better the paper the greater the success. It is seldom that anyone engaged in any technical calling prepares an essay on a set subject without an adequate gain in some way. The gain may not come at once, or soon, but it will arrive some time and remain.

Returning to the Society, the selection of a title was fortunate and appropriate, adopted, no doubt, because the membership was to be drawn from not more than one-fortieth part of the population of the whole country, and, consequently, under circumstances that precluded a division of professions and pursuits, such as can exist in the Eastern States, and in the populous countries of Europe. This scheme has proved a most fortunate one, because there is, perhaps, no other association of the kind that has worked more harmoniously and been more free from all kinds of dissensions, such as might have been apprehended, and is too common in associations of the kind.

The Society's history, for several years, was nearly what inference would assign. The ablest members presented able papers on the subjects with which they were most familiar, and then came a season of apathy. There was no effort to connect the Society's work with

the active industries and interests of community. It was a purely scientific association, such as this bustling utilitarian country is not yet ready for, and will not be for a long time to come. We can cultivate and promote scientific research in this country, and do so to a great extent, but not in the abstract, as it is done in Europe. There the commonwealth is the great fact of a country, here it is the person, and his business. Here everything to succeed must be connected in some way with the active affairs of life, and involve a factor of dollars and cents.

It is trusted that this is not an unfair criticism, or at least that it is true criticism. The purpose of its introduction here is to urge again upon the Society and its new board of directors the expediency of forming a permanent committee on arts and sciences, with the power of examining and reporting on new and useful inventions and discoveries, also on meritorious papers, and recommending the award by the Society of some kind of certificate or diploma, that will have a commercial as well as a scientific value to those who submit subjects.

There are objections to such a committee and procedure, but pitted against such objections are the facts that have just been reverted to, and our first duty is to make the Technical Society permanent and useful. In case unworthy subjects were submitted to such a committee, it is easy to ask the withdrawal of them without action. The Franklin Institute, of Philadelphia, has for many years — twenty, or more — maintained a committee of this kind, and the secretary of that institution will, no doubt, be glad to furnish information respecting the working and results of the "committee on arts and sciences," and the awards given in case of meritorious inventions. The adoption of a similar method here would require a good deal of consideration, and it might be some years before it would reach a practical working character. It is, however, worthy of serious consideration.

It would be agreeable to occupy a good deal of time in discussing this matter, but it is so eminently suited for general debate that I trust some of the members will, at an early day, present an essay on the subject, and thus arrive at a concensus of opinion respecting it.

In connection with this matter of a permanent committee on arts and sciences, or on new and meritorious improvements, which would be a better name, there is another matter that has engaged the attention of some of our members, and which can be recommended to the new board of directors for their consideration. I allude to lectures of a popular kind, in addition to set papers. By popular, is meant lectures technical in nature but popular in character, such as can be prepared or delivered without the research, computations and drawings, that are commonly required in our regular papers.

Such lectures, we have reason to believe, would be gladly contributed by members and others, if invited, and, in this manner, the Society would not only be brought into closer contact with the community and its interests, but it would relieve the membership from what is a severe tax on their resources.

It may seem an easy matter among a membership exceeding two hundred to secure monthly papers of a technical kind, such as should be published in the Society's bulletins, but it is not at all an easy matter. Such papers are expensive to prepare, and expensive to publish, and, under the present method, too many in number.

The American Society of Mechanical Engineers has a membership of 1,300, and holds two meetings each year. On the same basis that we attempt, this Society would produce seventy-two set papers each year, which, I need not say, is far in excess of the number presented.

In respect to the field in which the energy and influences of the Society are to operate, or to which its efforts are particularly directed, it will not be too much to claim that it is peculiar, or even anomalous. On this Coast the extent of engineering and technical work, in proportion to the population, is not only vastly more than in other communities of like extent, but is varied in a degree that has no parallel in any country.

These peculiar circumstances arise not only from a diversity that embraces nearly all the industries of our time, but to peculiarities of methods and requirements that arise out of climatic and other physical conditions peculiar to the Pacific Coast. I will mention only one, for illustration, the harvesting of wheat. This operation, which in most countries is no more than a farmers' problem, supplemented

by ordinary maunfacturing skill, becomes here, in California, an engineering one, involving peculiar machinery, immensely greater in size and power than is employed elsewhere, also with very different functions. The wheat is cut, threshed, and put into sacks at one operation, and by one machine, requiring as many as twenty-four horses, or equivalent steam power, to propel it. From 1,000 to 1,500 bushels are thus cut, cleaned and put into sacks in a day, by one machine, requiring, at most, the labor of five men, and is done, by contract, at a cost of not more than a cent a bushel. This is one fifth as much as the same operation costs in the Eastern States, and is only a tenth as much as in India, where the rate of wages is one fifteenth as much as in California.

Ten years ago the steam engines brought here for threshing failed to meet the requirements, and the manufacture was commenced in a number of different works in this State. Instead of 10 and 12 horse power engines, those of 40 horse power came into use. The furnaces and boilers were made for burning straw, on new methods, and the industry expanded to large proportions.

Later on the "combined" machines came into use, performing, as before explained, all the operations at one time, and just now the effort is being made to not only drive the threshing part of these machines by steam power, but to propel them as well.

One of the members of this Society has, during the past summer, spent large sums of money and several months of his time in the field studying the problem of operating these vast harvesting machines entirely by steam power.

The agencies and resources drawn into this single operation of harvesting wheat in California may well be set off against all that has been done elsewhere, the world over, during eight years past.

Most notable among the technical achievements of this Coast, and mainly among men who are members of this Society, has been the founding of naval architecture and marine engineering. It is hard to realize that this great and most difficult of all industries has been built up here in five years past, and in a manner not surpassed if equalled on this continent. The Union Iron Works have constructed some of the best vessels in the United States Navy, and of nearly all classes. On the 14th inst. the first rivets were driven in

battle ship *Oregon*, an armored vessel of 10,000 tons, and of the first class.

As a measure of the ability and skill brought to bear in this works, they pay nearly one cent a pound for transporting material from the East, eqnal to 30 per cent. of its value. They pay a rate of wages 33 per cent. greater, and yet have competed successfully with Eastern firms for these war vessels. With some knowledge of the subject at home and abroad, I will claim that their implements, methods and processes, also their management and engineering skill is superior to their competitors. It is a great industry, of which we may well be proud, and is ably supplemented here by the other works, where one may order a steamship, a locomotive, or a counter-shaft, and all will be made in due course.

There are other cases of the kind, among which may be mentioned a wonderful system of urban railways in San Francisco; sub-aqueous dredging by various ingenious machines. The development of tangential water wheels; the conduction and application of water under enormous heads, and, most of all, in the construction of large ocean steamers for both war and commerce. It is not necessary, however, to revert to these matters. The local record of engineering, architectural and mechanical achievement is extensive, creditable, and, as before said, out of all proportion to the sparse population of this Coast.

There is now rising into promise a new field that will, before long, tax the resources of the engineering professions; that of the conservation and distribution of water for the purpose of irrigation. Looking to what has been done in Egypt, India, Australia, and the mountain states of this country, and comparing with the future possibilities on this Coast, this problem becomes amazing in extent, and also in intricacy. Elsewhere irrigation is carried on under circumstances much more uniform in respect to varying precipitation, evaporation, varieties of soil, the torrential nature of streams, the volcanic and disturbed character of the earth where basins and canals are to be made, the peculiar and varied crops that are grown, and the lack of laws to define and regulate the control and apportionment of water.

There is, also, the great problem of supplying to commerce some other means of intercourse with the world than has hitherto been enjoyed, and without which all interests here must languish in future.

The best scheme, and incomparably the best one to improve the trade, and, consequently, all interests of this City, that has been presented in a public way, has been by an engineer, a charter member of this Society. Not only this, such presentation has been accompanied by certain propositions of an economical nature that serve to show the intimate relation between the technical and commercial branches of the subject.

The future of the Pacific Coast is mainly in the hands of those engaged in the technical professions. The problems are physical ones rather than commercial, and even if not, the commercial element has too close a relation with politics to much concern itself with the commonwealth. Commerce is competition, and a merchant's concern and ambition is apt to extend only to his immediate environment. He is not watching and studying the progress made elsewhere. That is no concern of his, so long as such progress does not interfere with his business.

I want to draw no disparaging comparison between technical, manufacturing, and commercial pursuits. All of them are necessary, interdependent and honorable, but what I do assert is that, in the nature of things we must look for progress and improvement elsewhere than in the distributing trades of this City.

The term commerce, we must remember, however, covers two very different pursuits. A merchant, in the true sense of that term, is one who equalizes and distributes the products of the earth. He moves the fruits of California to countries where such fruits do not grow; brings the tea of China here, where it cannot be produced. He carries out gold, silver, mercury, timber and salmon from the Pacific Coast and brings back in return iron, fuel, cloth, and various fine manufactures. This is commerce, and is something quite different from the distributing trades which divide and parcel out commodities in small or broken quantities to suit consumers. This branch of trade is what is called in England shop trading, and is the kind, I am sorry to say, best known here in San Francisco. The other kind, the merchant trade, will come with Mr. Dickie's steamers.

With this much of local and personal affairs, I will now attempt, in a compendious way, some review of the progress, discoveries, and great works of the past year.

The Nicaragua Canal I need not mention, as our committee appointed to watch and report upon progress made in this great work will, at an early time, present such facts as have interest to the Society. As to the national and economic phases of the subject, it may be remarked that there is a persistent effort to create another of those partnerships between the nation and private shareholders, which has proved so unsatisfactory in the past, and for which there is scarcely a precedent in any other country. The canal should be made either as a government work or as a private enterprise, perhaps the former, perhaps the latter, but certainly not a combination of the two, unless the money voted is considered as a bonus or gift to a company.

Government ownership, to the extent of an investment of public funds, sounds well as a business proposition, but, except the money advanced by the government to the Centennial Exhibition, at Philadelphia, I think it will be hard to show that funds, so loaned by the government have ever been paid back in kind, or otherwise.

The Manchester Canal, respecting which no estimates need be given here, is, no doubt, the greatest engineering work going on at this time, and is mentioned only to call attention to a very earnest inquiry in this country into the cost and advantages of inland water ways now engaging much attention all over the world. In this country there has recently been in Detroit, Michigan, a water-ways convention to consider the subject as it applies to the great chain of lakes, and their connections. A second convention of the kind has more recently assembled in Kansas City, Mo., to consider the improvement of navigation in the Mississippi valley, and the next in order should be a similar convention on this Coast to consider the navigation of the rivers in the great valley of California.

This consideration of waterways must, at first, be a commercial problem. Engineering facts will not have much interest until the cost of carriage compels such attention. In all countries, to some extent, but in this one to an enormous extent, the railway power has successfully pursued a policy and imposed restrictions that have

nearly destroyed river commerce, and the awakening of the last six months to some realization of this fact, portends, let us hope, greater movements for the future.

Closely allied with this is the subject of irrigation, or an artificial distribution of water, that will save, to some extent, the vast surplus that passes off to the sea, and which is, so to speak, the vital element of the principal industries on this Coast. Space will not permit a review in detail of what has been projected or done. The subject, in its latest phase, that is, on an extensive scale, is quite new in this country, but is as sure to be a field of much activity in the near future. In Egypt, the operations of British engineers are fast transforming that old country, and making it again as it was in ancient times, the seat of the most dense population that the world has ever known. The revenues from rented lands in Egypt, tributary to the canals was, last year, more than twenty-five millions of dollars. The population of the irrigated districts is set down at 5,800,000. The area watered is 8,840 square miles. In Australia the same work is going on successfully, and large grants of money have recently been voted in Victoria for irrigation purposes.

On this Coast, the problem of irrigation is much affected by the question of evaporation from impounded water, canals and ditches, and it was hoped that, during the past year, a paper bearing upon this subject would be presented before this Society, giving some data of value. The maximum evaporation set down for Madrid, in Spain, some portions of British India, and at Salt Lake, in Utah, approximates half an inch daily during the dryest periods, and during the summer months here must consume a great share of the water held or conveyed in the open air.

Great works and problems in civil engineering exist on all sides. Tunneling under rivers and straits has been reduced to an almost exact science. The great Liberian railway shows that no physical impediment can stop the path of the engineer.

The improvement of rivers and harbors by the general government I think had better not be mentioned. So far as this Coast is concerned, there seems no complaint, but on the Atlantic side the record is not one to call for commendation when compared with the achievements of private enterprise.

In mining engineering, which seems to embody nearly all other technical branches, a culmination of the art seems to have been reached on this Coast, or at least present effort has been narrowed down to details, and more directed to metallurgy, chemistry and geology, than to mechanical implements and processes. A mining engineer must be possessed of that qualification Mr. Carlyle called *gemeinlichewissenschaft*, or a knowledge of all things in general. A wide profession, with a wide field, and an eminent following on this Coast and in this Society. One of our active members has recently been appointed on the staff of the largest electrical company in the East, indicating what may be learned here by a young man not thirty years old.

The architects, who have always formed an important section of this Society, do not need mention, because their works show for themselves. The substitution of metal for masonry and wood, has rapidly called upon the profession for new qualifications of an extensive kind. Our City, and others on the Coast, even without streets, compare favorably in architecture with any others in the country, and the profession may well claim to be abreast with their co-workers elsewhere.

In mechanical engineering work, with which I am most familiar, the past year has produced, for one thing, a wide expansion of implements and processes for heavy forgings. Heretofore, this country has been much behind in what may be called heavy steel and iron working, but the great plant at Bethlehem, Pa., and others, have enabled orders to be filled for the heaviest forgings required for naval and war purposes. There has also been a great advance in the construction of small arms and ordnance, also in armor and other material of war.

It would be much preferable to mention such an expansion of inventions and methods to serve some useful and peaceful purpose, but at present in our own, as well as other nations, a large share of human effort is sacrificed on the altar of barbarism, and a spirit of destruction, that is sometimes mistakenly called patriotism.

As remarked, a great share of mechanical engineering effort has gone in this direction. The torpedo matter alone has absorbed much ingenious effort, and the expenditure of millions on a mode of war-

fare that should be deprecated among all civilized nations. These inventions and wealth for the destruction of human life and property, may be called an essential part of our civilization, but it is discouraging to think that about one fifth of human effort—one working day in five—must be devoted to such a purpose.

To mechanical engineering, in a sense, must be credited some of the efforts of the past year to accomplish aerial flight, and, for the first time, such effort has followed what may be called scientific methods. The only ultimate purpose to be gained, so far as now appears, will be a further contribution to the destructive fund, for war purposes. No engineer who has considered the matter, is likely to attach much importance to sustaining passengers and merchandise in a fluid that weighs .08 of a pound to a cubic foot, when the same weight can be rolled along on iron ways with a frictional resistance of ten to twenty pounds per ton. It is, I think, a field of inquiry that this Society may safely ignore.

There have been no startling discoveries in what may be called constructive engineering, and it may be safely doubted whether there ever will be in future. Evolution in the constructive arts is now narrowed down to matters of detail. Exact methods and computed results have supplanted empiricism and discovery. The world moves together in these things. There are no national lines. Technical knowledge has escaped race prejudices, the custom house, and ecclesiastical control. This Society is in touch with all others of its kind, in all parts of the world, and in this free interchange respecting technical research, rests the prodigious advances of our time in all of the useful arts.

Of that new and, I was going to say, magical field, electrical science, the past year has been more fruitful in adaptation than discovery, and when we consider that all the main phenomena and functions dealt with, are amenable to computed quantities and results, it is not likely that the period of discovery will be lengthened out over several ages, as in the case of older branches like steam, which is, even now, or until quite recently, less a science than electricity is.

The difference is in resources, as well as methods, or, as may be said, electrical science began where most other branches left off. There are many here, no doubt, who can remember when the thermal

problems in steam power were not thought of in practice, also when heat was only recognized as a condition of matter, and not an element of primal energy. It is not long ago, but was before electrical science came to the front, with even its nomenclature determined by the consensus of learned men.

This new science imposed an extensive draught upon the resources of practicing engineers, civil and mechanical. It was a new branch suddenly added, dealing with an intangible element, not amenable to their methods and implements, but pervading their field of practice. In colleges it added at least one fourth to the curriculum, and qualified, or affected indirectly much more. What its future connection with the industrial arts is to be, no one can foresee. Its relation to heat and light lies hidden in occult phenomena, and laws that give but little hope of early solution, but to be made plain some day no one can reasonably doubt.

If space permitted, it would be a pleasure to extend these remarks to various other technical pursuits; the production of high grade scientific and mathematical instruments, the thorough laboratory practice and other branches which our diversified membership embraces.

In conclusion it will be proper to revert to the fountain head, so to speak; the teachers, on whom depends the membership of this Society when our day has passed—the faculty of our technical colleges. They have, to a great extent, aided and promoted this Society by contributions, counsel and membership. To them we stand much indebted, and are anxious to increase the obligation.

In the wide and bewildering field, which has barely been hinted at, our Society must dig and delve after new truths, each member contributing his part, and here let me say that his part may be a very useful one, if he does no more than come to hear, and aid us with his presence. The courtesy that has marked the proceedings of the Technical Society is such, that no one need fear a respectful hearing of what he has to present, or say, and it is hoped in this term of 1892, there will be a wider participation in the proceedings by all, and especially the new members.

Some debate followed the Annual Address, after which the Secretary's annual report was presented, read and accepted. The report is as follows:

REPORT OF SECRETARY FOR 1891.

I have the honor to submit the following report of the condition of the Society and its progress during the past year:

The present total membership is 201; as follows:

Honorary members	2	Juniors	5
Members	177	Associates	17

Of these, 141 are resident, and 60 non-resident. A geographical distribution places in

San Francisco and vicinity	141	Illinois	1
Other parts of State of California	37	Massachusetts	1
Arizona	1	Minnesota	1
Colorado	1	New York	1
Idaho	1	District of Columbia	1
Nevada	3	England	1
Oregon	2	Hawaii	2
Washington	3	South Africa	2
Utah	1	South America	1

Professionally divided, there are:

Architects	4	Military Engineers	4
Builders	1	Mining Engineers	27
Chemists	5	Naval Architects,	1
Civil Engineers	73	Professors of University	5
Draughtsmen	2	Scientists	1
Electrical Engineers	2	Surveyors	7
Instrument Makers	2	Technologists	4
Marine Engineers	2	Associates of various callings	17
Mechanical Engineers	44	Total	201

During the year 1891 the Society increased in membership as follows: Admitted, 56; reinstated, 1; total, 57. Of these there are

Members	45	Juniors	4
Honorary Member	1	Associates	7

Professionally divided:

Chemists	1	Mechanical Engineers	11
Civil Engineers	23	Mining Engineers	3
Draughtsmen	2	Professors of University	2
Electrical Engineers	1	Surveyors	4
Honorary Members and Associates of various professions	8	Marine Engineers	2
		Total	57

[*Continued.*]

Membership of Society January, 1891:

Members and Associates	149	Increase in 1891	57
Total Membership in 1891	206	Resigned during 1891	5
Gain in 1891	52	Present membership	201

The resignations during the year are:

Alpheus Bull, San Francisco.
P. H. Jackson, San Francisco.
Thomas Hamlin, West Virginia.
J. G. Pohle, Denver.
A. W. von Schmidt, San Francisco.

The following juniors, entitled to full membership, will be placed on that list:

Franklin Booth. Ernest McCullough. R. E. Bush.

Number of regular meetings held during the past year	12	Directors' meetings	8
Public meetings	2	Special meetings	1
Number of addresses made	1	Number of papers read	14
		Discussion of topical questions	4

Papers were published in the printed preceedings of the past year on the following subjects:

Street Pavements in San Francisco.
Abrasive Processes in the Mechanic Arts.
Bridge Analysis.
Physical and Geological Traces of Permanent Cyclone Belts.
Hall's Hydro-Steam Elevator.
Cause of the Glacial Period.
Nicaragua Canal.
Act to Define the Duties of Land Surveyors.

Contributors:

John Richards. Naval Constructor Stahl, U. S. N. S. Harrison Smith.
Robert Hinchliffe. Jerome Newman. Marsden Manson.
Hubert Vischer. Louis Falkenau T. W. Morgan.
Irving M. Scott. Commander H. C. Taylor, U. S. N. George W. Dickie.

A board of examiners for State licensed surveyors was appointed by the Governor. The chairman and two of the members were chosen from the Technical Society, to-wit:

Luther Wagoner. S. Harrison Smith. L. F. Bassett.

Applications of 94 surveyors for a license were examined, acted upon and passed during the year.

OTTO VON GELDERN, *Secretary.*

TREASURER'S REPORT FOR 1891.

The report of the Treasurer was then presented and referred to the Committee on Finance.

To the President and Directors of the Technical Society of the Pacific Coast:

GENTLEMEN: I have the honor to make the following detailed report of collections and disbursements, assets and liabilities for the past year:

RECEIPTS.

Received from former Treasurer	$ 80 98
" " members for dues	1,478 00
" " admission fees	230 00
" " special subscriptions	192 50
" " room rent from Cal. Chapter Architects	60 00
" " sale of transactions of T. S. P. C.	57 50
" " " keys to room	3 30
Total	$2,102 28

DISBURSEMENTS AS PER VOUCHERS.

Room rent	$ 460 00
Secretary (13 months)	325 00
Collector	150 07
Janitor and office expenses	128 21
Stationery	33 45
Postage, carriage and duty on books	133 00
Printing and typewriting	510 47
Binding books	29 05
Engraving	69 25
Furniture, fixtures, and moving to present hall	259 90
Total	$2,098 40

ACCOUNTS RECEIVABLE.

Unpaid dues (to January 1st, 1892)	$ 542 50
Admission fees	55 00
For transactions T. S. P. C. (sold)	14 00
Keys	70
Room rent due from California Chapter Architects	20 00
Total	$632 20

ACCOUNTS PAYABLE.

Geo. Spaulding & Co. (printing)	$ 447 55
Britton & Rey (lithographing)	65 00
California Camera Club (furniture)	27 06
Edward Denny & Co. (stationery, etc.)	5 95
Advertising	5 70
Rent for December	40 00
Total	$591 26

Accounts receivable	$ 632 20
" payable	591 26
Balance	$40 94

SUMMARY.

Collections for the year	$2,102 28
Disbursements for the year	2,098 40
Balance	$3 88

GEO. F. SCHILD, *Treasurer*,

REPORT OF THE NICARAGUA CANAL COMMITTEE.

The Nicaragua Canal committee appointed by the President, consisting of Messrs. Ross E. Browne, A. T. Herrmann and Otto von Geldern, make the following report, which the chairman herewith submits:

A correspondence was begun with the manager of the company, in New York, who thereupon submitted to the Society copies of certain plans showing the location of the Atlantic section of the canal, with the topography of the country, and a corresponding profile of the proposed alignment. A general study has been made of the conditions from these drawings, but no official report has as yet been written. The Traffic Association, recently organized in San Francisco, has also taken up the subject of this canal. A committee has been appointed by that organization to discuss and report upon the commercial aspect of the enterprise, and to advocate this water-way as an advantage to the future ocean traffic of San Francisco, and as a means of improving the stagnation in the commercial conditions of California. Arrangements have been made with that committee by which the committee from the Technical Society will represent in any council the engineering features of this great project.

The work has therefore just begun, and whenever the matter is to be publicly discussed, our committee will have a full report to make, in which the physical and technical points of the proposed work will be explained as far as the accessible data will permit.

The committee therefore asks for further time, reporting progress.

OTTO VON GELDERN, *Chairman.*

TECHNICAL SOCIETY OF THE PACIFIC COAST.

SAN FRANCISCO, CALIFORNIA.

INSTITUTED APRIL, 1884.

TRANSACTIONS.

(VOLUME IX. No. 1.)

NOTE.—This Society is not responsible, as a body, for the statements and opinions advanced in any of its contributed publications.

THE COMMERCE OF SAN FRANCISCO.

No. II.

BY GEORGE W. DICKIE, MEM. TECH. SOC.

[Read Jan. 7, 1892.]

The Secretary, on behalf of the Technical Society, having written me to ascertain if I would be willing to read and discuss before you my recent publication on the "Commerce of San Francisco," I suggested that the pamphlet having already received some attention from the newspapers and the merchants, it would be better for me to assist the further discussion of this important subject by meeting the various objections and criticisms that have been sent me direct, or have appeared in the press.

In order to clear the atmosphere of anything personal, and enable us to meet the technical difficulties that have been raised to the establishment of a direct ocean steamship line from this port to New York and Liverpool, in their proper order, I will dispose first of the objections that have been raised against the parentage of this scheme. Suspicion lurks in some quarters, because the proposition for a steamship line comes from an engineer and a shipbuilder interested in a company which is supposed by these objectors to be backed by the railroad monopoly. If San Francisco desires an outlet for her products, and an entrance for her imports by her own Golden Gate, who are most likely to give sound advice as to the best instruments by which this desired result is to be accomplished? Is it not

those men who have given a life study to problems involved in the successful production of a modern ocean steamship?

The most successful steamship lines are those which keep on very intimate terms with the shipbuilder. If we want to dress well we take advice from our tailor in regard to the style of dress that will best suit us. If we want to erect a great building, that will be an honor to the City, we consult an architect who has had experience, and we carefully study the plans he proposes. So if the merchants of this City desire to make it the entry port for the western side of the United States, it can only be done by building a line of modern freight steamships expressly built for the special requirements of the trade, and, to do this, you need advice from your shipbuilders and engineers, so that, I think, we may take it for granted that the County Line comes from a poor, but honest and industrious parent.

In regard to the suspicion as to the place of its birth, it was natural for the newspapers to link my name with that of the Union Iron Works, although I expressly stated in my pamphlet that my work was that of an individual only. Nor need any suspicion be engendered on that account. Any statement made as to the connection of any of the Southern Pacific railroad people with the Union Iron Works Company has no foundation in fact. If the Union Iron Works has secured a good standing among the business concerns of this Coast, and among the shipbuilders of this country, it has not been by any backing from the outside, but is the result entirely of hard work and honest endeavor on the part of the Messrs. Scott and their associates.

Now, we will devote our attention to the "County Line," and why such ships were proposed. We will consider first the ships themselves, and second, the operating of them.

The question has been raised, both by letter and in the newspapers, why these vessels are proposed of such a size? In answering this question, I will not be tempted into discussing the steamship proposition of The Johnson-Locke Mercantile Company further than to notice one technical point, that has been presented in such a way as might lead to a misunderstanding. Having gone carefully through the specifications of their proposed vessel, I would not be justified in letting it pass unnoticed. I refer to the carrying capacity. Mr. Johnson (whom, by the way, I have not met) gives the carrying capacity of the vessel he proposes at 4,000 tons. Now the dimensions of the vessel, as specified, give a total dead weight carrying capacity, from the shipbuilder's light line, that is the flota-

tion line as the vessel leaves the builder's hands, to the deep load summer draught line allowed by Lloyds, of 4,180 tons, from this must be deducted sea stores of all kinds, dunnage, and coal for the voyage, this will reduce the cargo capacity, for dead weight freight, to about 3,500 tons. This statement is made in case it might be asked why there should be such a difference between the dimensions of a vessel to carry 6,000 tons and those of one to carry 4,000 tons, and for no other reason.

If our merchants do not at present want the "County Line" I trust they will help the Johnson-Locke Company. My purpose was to present to the merchants an outline plan of a vessel that would make regular and reasonably fast trips, with every appliance for the rapid handling of general freight, in fact a fast freight ship of the most modern type.

Ten years ago I advocated first-class freight steamships for this business, and this is the original plan made at that time, the only change I have made is to increase the indicated horse power by 500, and adding 1 foot 6 inches to the beam. At that time this plan was considered too far ahead of existing types of freight steamships, the transportation of freight on the Atlantic was then, for the most part, done by vessels carrying passengers, or by old passenger vessels that had become unfit for the higher class of work.

The Monarch Line has built some special freight steamships carrying about 4,000 tons; the cost of transportation was reduced, the great lines had to build special fast freight ships to enable them to keep in the business, so that now they have grown to about the dimensions I proposed for the San Francisco, New York and Liverpool trade.

Let me instance the development of the fast freight ships of the Oceanic Steam Navigation Co.'s ships, that is the White Star Line. I take this line because of their intimate connection with one of the most progressive shipbuilding firms in the world, Harlan & Wolff, of Belfast. In 1882 this Company felt the necessity of providing special freight vessels, and Harlan & Wolff were ordered to produce two vessels to carry 5,000 tons dead weight cargo, besides fuel, stores, etc. The result was the *Doric* and *Ionic*, both of which went into service in 1883, and are still in the service, and average nine round trips a year. The dimensions of these vessels are, length 440 feet, beam 44 feet, depth 31 feet 6 inches.

These vessels have the ordinary compound engines, and on that account burn more fuel than those of a later date. In 1887, Harlan & Wolff built another special freight vessel for the White Star Line—the

Cufic. In this vessel the only change in the dimensions made was adding one foot to the beam, making it 45 feet instead of 44. The engines, however, are triple expansion. This vessel carries 5,600 tons dead weight freight, less coal being required than in the older boats. In 1890, they built another boat for the same company. This vessel, the *Nomadic*, which commenced running about the middle of 1891, makes her trips in ten days; carries 6,800 tons dead weight freight, and is of the following dimensions: Length, 461 feet; beam, 49 feet; depth, 32 feet. This vessel makes 11½ knots, loaded, on 33 tons of coal per day. Compare the dimensions of this vessel with those of the *County of Contra Costa*, or those of the ship proposed ten years ago, and it will be observed that they are almost identical, so that what was then considered too far in advance, is now only abreast of the best practice.

In some communications to me, the rig of the proposed vessel has been objected to as being too heavy. Rapid and economical handling of freight is of great importance in a vessel of this character, and to be rapid it must be handled from all compartments at once. We have eight independent holds, and five masts are necessary to provide cargo booms for each hatch. To be economical, it must be handled by the ship's own tackle, and I have provided for its being so handled.

In regard to the sail power, the sail area relative to the flotation area of the vessel is about the same as that of the *City of Pekin*. When preparing the earlier plan for this vessel, I had some talk, in regard to sail power, with the late Captain Berry, then commanding the *City of Pekin*, and inquired how it was that he managed to make so good time with such a small developed horse power. He said that he never let any wind slip past his ship without getting some horse power out of it. Mr. Forsythe, who sailed as chief engineer with Captain Berry, will be able to tell us how the sails were used. It was in the hope that the class of captains to which Berry belonged were still on deck that the *County of Contra Costa* is shown square rigged on four masts.

The question has been asked: Why have a spar-decked vessel which is not usual in freight steamships, and adds to the register tonnage, and why carry all bulkheads to the spar deck?

In providing a spar deck, the first object was to provide ample space for a large amount of light freight, such a dried fruits, wool, etc., which must be kept dry, and must also be ventilated. It also gives the ship a good free board, enabling work to be done on deck

with some degree of comfort. Carrying the bulkheads intact to the spar deck, enables different classes of light freight to be kept separate. One kind might taint another if not separated by air-tight bulkheads. In case of fire, water can be used on one part of the cargo without any damage to another. Compartments can also be prepared for cold storage, if necessary. Shippers can secure independent compartments on certain decks for their own freight, and have it subject to a certain treatment on the voyage. The advantages of this arrangement will at once occur to shippers whose goods must not be subjected to the possibility of taint from other materials while on ship board.

The possibility of making the voyage in the time stated, and on the fuel provided, has been questioned. One evening newspaper, in an article published on the 26th of last month, takes, for an example, the case of the *Alameda*, which made the voyage from New York, without any stoppage, in 59 days, and this vessel averaged 13 knots per hour, and asks, triumphantly, how the *County of Contra Costa* is going to cover the same distance in 50 days, making 11 knots? Now, this party who demolishes my figures so cleverly, evidently knows it all by heart without any figuring; he deals with known facts, and you know that there is only one thing more misleading than figures, and that is facts. Now, here are two facts stated: 59 days and 13 knots, that is 312 knots per day, and 59 days at that rate would be 18,408 knots, that makes some trouble about these facts. If we take the fact of 59 days and the true distance, then the average speed was $9\frac{2}{10}$ knots per hour; if we take the other fact of 13 knots, then the time was 41 days and 16 hours. This writer, having disposed of my figures with his facts and, as he says, having shown me wrong in one item, concludes I must be wrong in all. We will not dismiss him in that way, but will refer to him again as occasion requires.

As an instance of what may be expected on a long voyage like this, with a ship specially designed for the purpose, I will give the first voyage out of the new freight steamship *Tekoa*, just built by Gray, of West Hartlepool, for the New Zealand Shipping Company, to run between London and Auckland. (Imagine little Auckland having ships that San Francisco can't afford). This vessel is 469 feet long, 49 feet 3 inches beam, and 33 feet deep; engines triple expansion, 27″ and 43″ and 72″×45″ stroke. Compare this ship and engines with the *County of Contra Costa*, and see how closely they approximate to each other.

This vessel left London a little over three months ago with 6,250 tons of dead weight freight, and 1,400 tons of coal in the bunkers, steamed 12,059 knots without any stop whatever in $50\frac{9}{10}$ days; average speed $9\frac{87}{100}$ knots per hour; coal consumed $1,081\frac{3}{10}$ tons, or $21\frac{1}{4}$ tons per day. This is a splendid result in fuel, considerably better than I expected to do in the *County of Contra Costa*, and it shows that 50 days is not only a possible time for the voyage from here to New York or Liverpool, but for a modern ship it can be done at a very economical expenditure of fuel.

Having considered the first question, that relating to the ships themselves, we will now consider the second question, that of operating them. Can these vessels be operated with any degree of certainty on the total expense allowed in my estimate? None of the communications to me have questioned the expense, but the article already referred to, in an evening newspaper, appears to have some weight in certain quarters, and therefore requires to be answered.

The first question asked is "why has no allowance been made for insurance of hull?" The writer of this newspaper article has not dealt with my pamphlet as it is, but has it mixed up with another proposition on page 11, suggesting the method of ownership of the proposed vessel. I provide that each owner can handle his own share as it suits him, can dispose of it as he pleases, can insure it or carry the risk as he sees fit, and on page 15 in stating that the amount divided would equal about 24 per cent. per annum, it is also given about 6 per cent. less to owners who insure. The question of time to make a voyage has already been noticed.

The next question raised is the time allowed for loading and unloading. The reference that this writer makes to time in way ports need not be considered, as no mention is made of way ports in the pamphlet. My proposition was for a direct line, but should there be business for way ports the time required at such ports would be added to the 50 days at sea and deducted from the 50 days in ports.

Our friend figures that on a round voyage, carrying 6,000 tons each way, 18,000 tons must be handled, and I forgot that fact for I had calculated on having to handle 24,000 tons. We will not discuss this question with the stevedores at present, but will refer to the time taken in port by similar vessels, referring again to the trans-Atlantic new freight steamer the *Nomadic*. I find that this vessel makes a complete round trip in 40 days; 22 days at sea and 9 days in port at each end, and carries 6,800 tons cargo. Here is 27,200 tons

of freight handled in 18 days, and the "County Line" people cannot handle 24,000 tons in 50 days.

If this writer had cared to inquire around our own docks he could have obtained some facts on handling freight not quite in accord with his conclusions. The Pacific Mail Line ships from this port to China, are near the size of vessel we propose, and being also passenger vessels, are very poorly adapted for handling freight, yet if these vessels are on schedule time they have but 15 days in port to discharge and load coal, and do any repairs that may be required, and when occasion requires, as in the last trip of the *City of Pekin*, on account of going into quarantine, it can be done in half the time. The Occidental and Oriental chartered vessels, belonging to the White Star Line, in the same trade with this port and China, if they are on time, have 16 days in port, and as to going like clock work (as this writer seems to think outside of the possibilities), the White Star steamers, running from here to China, do run like clockwork, none of them having missed a sailing day for years.

The next question raised is that of port charges. Nothing is allowed, it is said, for loading and discharging. The amount to be paid for labor under this head was included partly under the head of port charges and partly under the head of wages. It will be observed that the full crew is maintained during the whole time in port, and provision account is also for the full force the full time. The cargo would be handled as it is on all such vessels, by the ship's own appliances, under charge of the ship's crew, outside help being engaged for breaking out and stowing cargo. If the crew leave the vessel more help would be required outside, but the wages bill on the ship would be less, and less provisions would be consumed; $1,400 was the amount allowed for outside help in handling freight in port. The New York freight steamers of the highest class allow 8 cents per ton for this work. I have allowed 12 cents, which would allow 16 cents at San Francisco and 8 cents at New York. Regarding the wharfage at San Francisco, this writer places it at $1,749.75. Now the per diem dockage of a vessel in this harbor is $4.00 for the first 200 tons, and ¾ of a cent for each additional *net* register ton. Vessels lying idle, or taking in cargo, are subject to only half rates. Our vessel would be 8 days subject to full rates, and 17 days subject to half rates, that is if the line could not lease wharf accommodation.

The net register tonnage, according to the plans, would be about 3,800. That would make the full rate dockage $31.00 per day; 8

days equals $248.00; 17 days, at half rate, equals $263.50, or a total dockage bill of $511.50; this leaves $1,088.50 for pilotage, the service of a tug, if necessary, and such things as would not be classed as incidentals. The dry docking of the vessel, which I had provided for at the outward end of the voyage as a mere matter of modesty, is also questioned, the writer stating that I had provided $5,200 for port charges and dry docking at Liverpool. The actual figures given in my estimate are $5,800.00. The intention was to use white zinc and tallow for the bottom. Material and labor for this work would cost in Liverpool $550.00, in San Francisco, $850.00. The dock dues for two days in Liverpool would be $1,392.00. Dock dues for two days, at present rates in San Francisco, would be $2,320.00. $2,800.00 having been allowed for docking and painting in Liverpool, deduct the cost of labor and material in San Francisco, leaves $1,950.00 for dock dues, should the vessel be docked here. Ten ships, docked once in five months each, would be 24 dockages, making $46,800.00 a year for dock dues.

The California dry dock people, I think, would be willing to contract now for the use of their dock at such rates. If an Atlantic freight steamship, say the *Nomadic*, incurred port charges equal to what I have allowed for the *County of Contra Costra*, it would equal $1.77 per ton of freight she carried, and this comes very near to equaling the rate at which she carries freight. In fact, I had made my estimate high to be perfectly safe.

There are other points brought up in the article referred to, which is really a very clever presentation of the objector's side of the case. He ingeniously works in the shippers' insurance on the goods shipped as part of the operating expenses of the ship. If his argument were for a higher rate of freight by rail than by sea, his point would be well taken, except for freight that has to cross the Atlantic before going on the rail, as the railway companies insure the freight while in their hands—the steamship owner does not.

Next the revenue of the County Line is questioned. According to this writer the competition is to be, not with rail freight but with the sailing vessel, and yet he advocates a competing railroad to relieve the distress of our merchants. Is this new railroad also to compete with the sailing ships? He says "dry goods merchants must have their goods from Europe in as quick time as ocean greyhounds and fast railway freight trains can bring them hither." Again he says "when the steamer arrives here they would have to wait a week or two until their goods were brought up out of the

hold." Let us investigate this poetical statement a little. How is it that this merchant who is in such a hurry for his goods, gets them out of the same kind of a ship's hold in New York, without any loss of time, while the same operation takes one or two weeks here? More than that, he generally ships from New York by the Sunset Route, so the merchant who is in such a hurry, according to this writer, must wait two weeks to get his goods out of the ship's hold in New York, ship them into another vessel, which, according to this authority, must be ten days loading, for they take 4,000 tons, then another ten days again to get them out of the ship at New Orleans before they get on to his railway.

Again, he says: "The merchants cannot afford to run the risk of almost certain delay in the voyage by the Straits of Magellan. They, with the fine leather merchants, with carpet dealers, even the hardware men, in many kinds of hardware, cannot afford to run the risk of damage by sea. For however closely a vessel may be constructed, the goods in the hold are sure to be damaged to a certain extent by leakage." This is a sad commentary on the ability of our ship builders to construct ships that will keep cargoes dry, yet these very dry goods merchants, leather merchants, carpet merchants, and even the hardware men, are just the men we want to carry freight for at $10.00 per ton, and they are not so much afraid of salt water either, for they ship at Havre and Liverpool on fine freight steamships like the "County Line" across the stormy North Atlantic, where their decks are often covered by seas all the way across, and ship them again on another steamship to New Orleans, and all without damage by water, and at from four to six times the cost at which it can be done by the "County Line."

Our ships might have to carry some classes of freight at five to six dollars per ton, but the freight that is now crushed by railroad rates, and that must be moved quicker than the sailing ship can do it, is just the freight that can afford to pay good steamship rates. As it must take the same time to get goods into or out of any two ships of the same character, and each fitted with the same facilities for handling freight, the question will present itself to the merchant something like this: To import goods from Europe by the present arrangements the time will be: 3 days to load, 11 days to cross the Atlantic in one of the first-class freight steamships; 4 days to discharge in New York; 2 days to load on Sunset steamer; 18 days from New York to San Francisco, and 1 day for delivery; total, 39 days—as the shortest possible time. To ship by the County Line

would be: 3 days to load; 50 days to San Francisco; 4 days to deliver; total, 57 days. Now, if the difference between 130 days by sail and 57 days by steamship is not worth any difference in freight rate, why should the difference between 130 days by sail, and 39 days of steamship and rail be worth ten times the rate of freight?

A correspondent writes me that while the steamship line would be a present relief to the commerce of San Francisco, yet the salvation of the San Francisco merchant can only come with the completion of a canal which would cut the steamship time down to 27 days. While my correspondent is right, we must remember that if the means were already secured to construct the canal, it would be ten years before one of our steamships could pass through. We have already seen that the ships we propose are similar to the best types of freight steamships, for shorter routes, so that when the time comes when a steamship can go through the canal, the "County Line" will be as suitable for the business as anything that floats.

I have not exhausted this subject by any means, nor have I touched on all points that have been brought out in connection with the discussion that has been going on in the newspapers, but I have said enough to bring this subject properly before the Society, and draw from those present, who are interested, such an expression of opinion as will clear up many points on which the public are not very well informed. I trust the discussion will be without reserve, as I understand the Society makes this an open night, non-members having a right to take part.

After reading the paper, Mr. Dickie added the following:

"Some time ago in talking with a ship captain about the different ports for sailing vessels, he said that San Francisco was about the only port that was left unravished by steamships. I asked 'what is the reason San Francisco has been left out?' He replied 'I don't know, unless it be that the shippers and the merchants of San Francisco have not found out yet that ships are propelled by steam. If they ever find out that ships are propelled by steam our business is gone.'" Mr. Dickie added he would be glad to receive questions and criticisms from both members and non-members.

DISCUSSION.

Mr. Manson.—"Mr. President, I think we owe a good deal to Mr. Dickie for bringing up this question at this particular time. The last time this Society met in this hall one of the naval officers of the United States Navy pointed out to the Society, and to this

community, the advantages to be derived from the construction of the Nicaragua Canal. Mr. Dickie touched on that, and showed the importance of San Francisco owning and operating, for San Francisco, her own ships. Ninety per cent. of the vessels that come to this port are not run for San Francisco, but simply to get as much out of our merchants as they can, just as the railroads do. We might as well understand the fact that they are not going to reduce rates until the merchants themselves get together and force them to do so. I would like to see a railroad running out of Chicago attempt to discriminate against the Chicago merchants; Chicago would have the railroad in the hands of a receiver in no time. The Board of Trade and other bodies of citizens would not allow that railroad to exist.

Now the Suez Canal, the Panama Canal, or the Nicaragua Canal, are not going to do us any good unless we own the steamships that run to, and in the interest of San Francisco. We are here on the borders of an ocean with 80,000,000 of square miles of water, and the wealth around that ocean is untold, and we own no great line of steamers, not even a line of sailing vessels. We sit down here and prate about the benefits that a canal, constructed by somebody else, will give us through the ships of somebody else. I think Mr. Dickie has struck the nail as squarely on the head as he possibly can do, in calling attention to the fact that we want to own and operate our own steamships for our own interests."

CAPT. W. L. MERRY.—" Mr. President and Gentlemen: I did not come here to talk, but to listen. The subject is a very old one to me. I spent sixteen years of my life at sea, and for seven years I was in command of ocean steamers. They had side wheels, long stroke, and consequntly now are behind the age.

In the first place there is not the slightest doubt that steam carriage by sea is as cheap as any transportation known to commerce, and especially for short voyages the steamship can compete with sailing vessels. The steamers we are now commencing to build which run at a low rate of speed—about ten knots an hour, for the carrying trade, can compete with sailing vessels on long voyages.

As San Francisco is a sea port her development must come from the use of her sea board. It cannot be accomplished through the railways. They can approach only from one side, it is not a center with railroads reaching out in all directions.

An ordinary ship takes 3,000 tons of freight, and that will load 30 trains of 10 cars each.

Now this question of Mr. Dickie's is an interesting one, because it is a solution of the great need of San Francisco at the present time. Of course it will obtain its best results with a shorter trip through the canal. That will, no doubt, be the ultimate solution. At present, however, the route is the worst one of the world, because it is the longest route; and, as I have said before, the longer the route the greater the disadvantage the steamship has to compete with. There is no voyage in the world, that I know of, that is harder on the steamship than from New York around Cape Horn to San Francisco, on account of its length, crossing the equator twice and passing through the heat of the tropics.

The pamphlet published by Mr. Dickie I have read with great interest. I differ from him in some respects, but in the main I agree with him. I, however, suggested to him that, according to my American ideas, I was in favor of a little more beam, and suggested twin screws, so that in case one should break down the other could keep the ship going.

I have another objection, and that is the ship's name. A ship was building up in Maine somewhere, and the Captain visited Boston to report to the owner how it was getting along, he reported that it was nearly ready to launch and asked that they select a name. The owners told him they wanted a short name, one that was easily spelled, pronounced and written, and any name that would meet these requirements would be satisfactory, and requested him to select one. When the captain came to Boston again he was asked what name he had given to the ship. He replied, 'I thought of all your requirements, and after thinking the matter all over I called it the *Ox*, you can't find anything better than that.' But this is not a part of the argument. I should select shorter names simply to save time. The ships are long enough without having such long names.

The question is one of great interest to San Francisco. But if you go to the merchant today and say to him, 'here is a steamer that will land your freight with reasonable certainty in 60 days, and the sailing ship will land your freight with less certainty in 130 days, how much more will you pay for the reduction in time and an increased certainty in delivery?' do you know that man will say very little. I have been astonished to see how little they would say. They appear to think that the saving of time and the additional certainty of delivery is a matter that does not incur a great deal of extra expense; consequently they do not give the encouragement

necessary for men to invest in anything of the sort. They are apparently oblivious to the fact that the saving in time and the greater certainty of delivery is a great factor.

From all that I can gather, the question at best is a very close one. I think a steamship line from here to New York, with modern steamships, could be made to pay 8 per cent. per annum on the cost of vessels and operating expenses.

According to the laws of this State vessels registered here are taxed their full value. New York has no laws of this kind, and in Massachusetts if the ship earns nothing she pays nothing. Here a ship worth $1,000,000 is taxed $27,500 a year. If you had them here you would register them in New York and Boston to avoid that taxation. The policy of this country has been to damn the shipping industry and foster railroads. When I was a boy we were a maritime nation. England is a maritime nation, but without her ships she would be nowhere. We are a great country without ships, consequently we do not depend upon ships as I think we ought to for our own benefit and our own advantage. But San Francisco is not so much to blame; generally money can be better employed than in shipping, it can find better investment. When I was a boy everything was done to build up American commerce. We had all kinds of legislation for the encouragement of shipping. We have stopped encouraging shipping in any shape, and then we ask why we have no ships. On the contrary we legislate for railroads, and give them enormous land grants. Until these conditions are changed we will never have successful shipping.

I will be delighted to have San Francisco take up this question, but until the voyage is shortened by a canal there can be no large fortunes made in this direction, in my opinion. I think by economical management there might be a return of 6 or 8 per cent. In the main I am in sympathy with the ideas of the speaker."

CAPT. GOODALL.—"I did not come here to address the Technical Society; I believe rather in a practical operation, and the technicalities I am disposed to omit. Not being sufficiently acquainted with these I leave them to the wise engineers, who consider these matters at their leisure, and make a very fine effort when they tell us about them.

I want to lay Mr. Dickie's plan on the shelf, so far as the Liverpool proposition is concerned. If it is so practical to run steamers, such as he has planned, to Liverpool, there would be no difficulty in the way of English people running their tramps here at

once. They have acres and acres of vessels lying still, waiting for something to do. (They had when I was last in Liverpool, and I think they have at the present time.) They have shops and shops, boiler shops and machine shops, and shipyards. They want business of this kind, they want ships to build, and they will build them for about half what Mr. Dickie proposes to charge for building the same ship. When they get them built they will run them for about 60 per cent. of what they can be run under the American flag, and owned in San Francisco. An English ship with an English crew, and English living, black bread, barley soup, and mahogany for meat differs from an American ship with condensed milk, fresh butter, and mince pie. It soon amounts to a difference of 60 and 100 per cent. Therefore I say it is impossible that Mr. Dickie's ships can run to Liverpool and pay.

As to New York, that is a different proposition, but the question is whether the railroads would allow it to be done. The railroads have five tracks now running between this Coast and the East in some manner or other; therefore they have found it necessary to raise the freight. With more roads, and an increased number of officers and offices, they must have increased operating expenses; hence a higher rate of freight. They are not going to take their tracks up. They are insane on what they call the 'long haul.' They would rather haul a ton a hundred miles than twenty miles, just for the sake of having a 'long haul,' if they can get the same price for it. Mr. Huntington, in his letter in the *North American Review*, says the law regarding this matter of the 'long haul,' is unjust; that the railroads should be allowed to run the steamships off because they can go somewhere else to make a living when the railroads cannot. A railroad has to confine its business to its particular track. That is Mr. Huntington's theory, because he is a railroad man; my theory is that this should not be allowed, because I am a steamboat man. As soon as steamships reduce freights they will make a strong fight. They will do the best they can under the circumstances. Railroads are run to make money, exactly as you run your mercantile operations, the Union Iron Works, and everybody else carries on his business to make money. When the railroad has run your steamships off then the people will have to pay higher rates to make up the loss of the railroad during the competition.

One more proposition: I don't think Mr. Dickie can run the ship as cheap as he imagines. He knows how to *build* the ships, and

build them very cheaply; but I have had some experience in *running* his ships. He estimates, for engines of 2,200 horse power, a consumption of 1½ pounds of coal per hour per horse power. Now we had one of the finest ships that Mr. Dickie ever built, and it takes 2½ pounds of coal to the horse power per hour. We also had an engine made by him put into the steamer *George W. Elder*, which is somewhat smaller than those he proposes to build. She made a trip to Callao when there was trouble there, and she made 8¾ knots per hour, and burned 15¼ tons of coal in 24 hours. They were modern engines, which Mr. Dickie built or designed himself —a splendid piece of work; as fine as can be made anywhere. I don't think his "County Line" could have any better. I don't see how he is to run these larger vessels at the rate of 10 or 11 knots an hour and carry 6,000 tons of cargo on his allowance of coal.

Mr. Dickie is a little behind in the number of miles from here to New York. We had three ships make the trip that averaged 13,600 miles coming through the Straits of Magellan. According to Mr. Dickie's figuring he would be about two days away from New York when he thinks he is there.

There is no doubt that Mr. Dickie is all right about the building; he has money enough for that—$680,000. I own a little in the Union Iron Works, and I hope he will get one to build at that price, for then I would get my share of the profits.

Somebody else has written an article in the papers giving the cost and profits of smaller vessels than Mr. Dickie proposes. This writer puts down $220,000 as the cost of building a steamship carrying 4,000 tons, and running that ship on something like 14 tons of coal a day, and getting 10 knots an hour. It seems to me that is a hair-brained proposition, too. I think there is a mistake about this business, and I shall have to take issue with Mr. Dickie in the matter of running expenses."

W. L. MERRY.—"There are one or two points that I cannot agree upon with Captain Goodall. In small steamers there is always a disadvantage in carrying freight as compared with larger ones.

As to the distance between here and New York, I have investigated that very thoroughly, it averaged through the Straits of Magellan, 13,560 or 13,580 miles. But these are nautical, not statute miles, which makes quite an essential difference.

The criticisms he has made by comparisons with the *George W. Elder* are hardly fair; between this and the ship Mr. Dickie proposes to build there is an enormous difference in the type and character

of freight it will carry, and in the tonnage. I have no doubt it would show a greater capacity and less use of coal. I don't think it is a fair comparison to make between these two classes of vessels."

CAPT. GOODALL.—"I made a reference to a brand new ship planned and built from bottom to top by Mr. Dickie, and what he does not know about building ships and engines no one knows. The little ship called the *Pomona* developed about 1,000 horse power, and burns 2½ pounds of coal to each. She makes about 13 knots an hour."

MR. DICKIE—"The main point made in this discussion, and it is a very important one, has been made by my venerable friend the Captain, in regard to the consumption of coal. Now I stated in my pamphlet that the fuel was first-class steam coal, that the estimate was based on Cardiff coal, and the price allowed that paid for Cardiff coal at both ends, delivered to the ship. Now other vessels of the same size as this ship are doing this work, and doing it every day on the fuel that I have proposed. The horse power requisite for the speed is 2,200 for a vessel carrying 6,000 tons of freight. Captain Goodall's vessel carrying 1,200 tons of freight requires 1,000 horse power, although a development of 700 horse power would give the same speed that I propose.

I am referring now to the *Pomona*, and the Captain's statement of the consumption of fuel on that vessel needs some explanation, otherwise this statement might be compared with the consumption on other vessels, and our reputation suffer in consequence. Having seen the Captain's computation of fuel burned, I am in a position to explain how he arrives at the result of 2½ pounds of coal burned per horse power developed.

The *Pomona*, running in the Eureka trade, averages 43 hours running time, that is from the time the captain gives the go ahead bell to the time he slows down at the other end the average time has been 21½ hours. Now, so much coal is placed on board for the round voyage for all purposes, this amount the Captain divides by 43 hours, and then by the horse power shown by the cards taken during the trip. Before he made his computation against the consumption per horse power of the engines, he should have deducted the fuel required to get up steam in San Francisco, the amount used in a donkey boiler, taking in freight, the amount used in the kitchen on the voyage up, the amount used in Eureka hoisting out and in freight, and getting up steam for the down trip, and the amount used in the kitchen on the way down. With these deductions

he will find the consumption of even the poor quality he uses not more than 1¾ pounds per horse power per hour on the *Pomona;* the percentage used in ports where the voyage is less than one day is very great, and this case will not compare with that of a 50-day voyage. The power does not increase as the displacement, but with the skin resistance of the vessel—the wetted surface, and some other factors that enter into it.

Now I have stated in figures tonight the facts. Here are vessels crossing the Atlantic carrying the amount of freight I propose for these vessels, and they burn the amount of fuel I have allowed. Two of the larger vessels on the Atlantic, of the White Star Line, have developed a horse power for less than 1½ pounds of coal. It depends upon the kind of coal that is burned. Capt. Goodall knows that the kind of coal used in his vessels is not the same as would be used for an economical long ocean voyage. These vessels must have steam coal, Cardiff coal. With that kind of coal and the proper means for burning it, the consumption will be, in fact, less than what I have stated.

Regarding the distance the vessel would have to run, I was in error. I had assumed 13,060 nautical miles as the distance. That would make a difference of three eighths of a knot of speed in the vessel to make the time I have stated. But the amount of coal provided was sufficient for six days more voyage than the time given for the ship. The statement of power, and the statement of fuel consumed upon a freight steamer that has just made her first trip to Auckland, I know to be correct. Her consumption of coal was slightly under 1½ pounds in the development of horse power up to 1,700.

As to the certainty of long voyages, the Orient Steamship Co., whose ships run about the same distance, are very regular in their sailing days. The voyage to the Australian Colonies from England is nearly as long as the voyage around our continent by the Straits, but not as severe. The modern steamships can be made just as reliable as the railroad train. They are subject to accidents, but these accidents are not of so frequent occurrence as one would suppose, that is, in vessels that have been built expressly for the business.

Reference has been made to a vessel that came in here, for a few days, that made an exceedingly long trip around the Horn. That vessel is not fit for any kind of business. If we propose to carry freight from San Francisco to Europe or New York, or from these ports, in such vessels, we will meet with failure, and we can't do

otherwise. The idea of cheap ships ever being employed in this traffic must be abandoned, for it will never succeed.

It has been stated here tonight that ships could be built in England for half the price I have stated. I happen to know the prices of several ships on the White Star Line. One of the steamers cost $584,000, and she is 20 feet shorter than the ship I propose. It has the same outlines and engines exactly. That vessel is employed between Liverpool and New York, and the average amount paid for freight carried in that vessel is less than $2.50.

Captain Goodall says these ships would be run out of the business by the railroads, who would reduce the freight. Well, this is one way of getting even with the railroads, if the railroads reduce the freights you have only to keep the steamships going to keep freights reduced.

There is a deeper question than that. No company can run at a loss except for a short time, or for a certain purpose; they cannot do it forever; the railroads must earn enough to pay running expenses. Now it takes the same amount of fuel to carry one ton a mile on the railroads in this country as it does to carry the same amount 20 miles on an ocean steamship of the latest make. Such are the statistics in England, and they have been compiled very carefully. Now it is simply a question of endurance. I hardly think it is possible that they can come under a cent a pound for freight and pay expenses. When the Sunset route was opened, the railroad people were going to carry the wheat that way to New Orleans, and ship from New Orleans to England at $10 a ton, and that is the freight I proposed for these vessels. The question is simply this, is $10 a ton reasonable for carrying goods from New York to San Francisco, or from England to San Francisco on 50 or 55 days' time? If that is a reasonable freight then the steamships can do it, and do it profitably. That is really the only question. The railroads cannot do it profitably at that price. If the fact of a few steamships would reduce the charges for freight on the railroads for all trans-continental freight, it would pay to keep them running even if they carried nothing. They could run opposition to Captain Goodall now and then, to keep up the status of the concern.

The cost of building ships and the cost of running them is a matter that can be brought down to figures, and the statement that a vessel of the size I propose can be built in England for $200,000, or $300,000, has no foundation in fact. We are not talking of tramp

steamers, but of first-class freight steamships, and they do not compare with each other at all.

Captain Merry raises a question which I think the most important raised tonight. That we have to pay a large amount of the earnings of our steamships for taxes. Now this is a matter that lies entirely with the people themselves; they make the taxes; and if it is a good thing for San Francisco to have steamships, they can legislate to remove the tax on steamships.

CAPT. MERRY.—"I will state in that connection that the new Constitution stands in the way, for it says all property shall be taxed. It is a question of getting a new Constitution, and that is a very hard matter to do. I would be pleased to see it. It is now simply a matter of registering somewhere else. The Pacific Mail steamships are all registered in New York."

MR. DICKIE.—"I may state about the cost of ships for the U. S. Navy, now building here, that if the material for them were brought on steamships for $10 a ton from where it is manufactured, it would reduce the price of one of these vessels in San Francisco $46,000. That is the difference between carrying this freight by steamship and by rail. We are building a warship of 10,000 tons displacement for the U. S. Government; if the material that comes from the East for that vessel could be brought by sea in the time that I have stated, and at the rate of freight I have stated, on that one ship it would make a saving of $97,000. Now, there is money in this matter of carrying freight. It would pay to run a steamship to get the railroad people down to the same rates under these circumstances."

W. L. MERRY.—"What do you consider the difference in cost in the building a first-class ship in Philadelphia compared with the cost of the same ship built at Liverpool. I see that Cramp says in an article in the *North American Review* that he can build as cheaply as in England."

MR. DICKIE.—"I understand him to mean that a ship of a special class he can build as cheaply as they can in England. They can build an English ship cheaper than we can. For instance, Elder & Co. can build an Elder ship cheaper than we. To build *the same* vessel cannot be done as cheaply here as there. The material and the labor cost about twice as much; the main difference is, the ship builder gets a larger profit in England than he gets here. There are ship builders and ship builders in England, and it is very difficult to predict what would be the price of a vessel. The White Star people have been offered between $600,000 and $700,000

for a vessel that has been running over 22 years, and it is almost as much as the vessel cost, and yet it could not be bought.

Vessels for special purposes are not cheaply built in England; but vessels that are standard ships and built by the dozen by everybody, and where no reputation is involved in the building, and when they are lost no one asks who built them — such vessels are built very cheaply."

CAPT. GOODALL.—"What do you think of a ship constructed to carry both freight and passengers, and to stop at Callao, Valparaiso, and Rio Janeiro?"

MR. DICKIE.—"A ship carrying passengers as well as freight, and stopping at way ports, is a subject that is not in our programme tonight. That is a matter of steamship management more than steamship building. It is a question I have not sufficient knowledge of to give information that would be worth anything."

CAPT. GOODALL.—"In my opinion, that is the practical way to do the business. A large trade could be developed between these way ports at good prices, and if the railway people compete on the long route, the local business can keep the ships running."

CAPT. MERRY.—"I made several trips to Australia in sailing ships chartered by British merchants, and at that time that work was done by large clipper ships. That was along about 1859 or 1860. This business has now entirely left the sailing ships, and there are very few in that trade, the steamships have taken it away. That is more analogous to our ocean route than any other. The voyage is long, and a portion of it is tempestuous; but notwithstanding that fact the lines of steamers between Australia and England have absolutely run those sailing vessels off, and many are now hunting trade from San Francisco.

Another point I wish to mention is this: Mr. Huntington is a very astute man; he is probably one of the best financiers in railroading and one of the shrewdest operators that this country has produced. That man, when he saw he had to make a fight on overland traffic, notwithstanding he owned a railway from Newport to New Orleans, practically had his connection from Newport to New York, he bought out the Morgan line of steamships between New York and New Orleans, for the express purpose of making that fight and beating the overland railroads; and notwithstanding that route is attended with several difficulties, he has been able thereby to dictate the policy of the overland companies crossing the continent. When you come down to the basic fact, water transportation will

always beat railways when time alone is not requisite. It is Nature's highway—it is God's highway; it requires no tracks; it is free to everybody, and when we consider how much greater the operating expenses of a railway are than running ships, we can see how difficult it will be for railways to compete. Water transportation will always beat the railways, provided there is an opportunity to put the ships on, and getting freight for them. I think that is a demonstrated fact.

I tell you, gentlemen, this is really the solution of the position of this port. It will never be a railway center, from the fact that we are at the end of a long haul, and can have railways only on one side of us. As a seaport we have great advantages at our command. Until this is made a seaport in the full acceptation of the term, San Francisco will never be what her locality should entitle her to be in future."

DISCUSSION OF TOPICAL QUESTIONS.

[Held Dec. 4th, 1891. From stenographic report.]

The following question was submitted:

How can we account for the fact that machine work in San Francisco is, with few exceptions, not made to standard sizes?

MR. RICHARDS.—"I am qualified in one way to say something upon this subject, that of always having felt a great interest in it, and have never been able to discover a single reason why work in San Francisco should be made to no standard whatever, of any kind. As to giving you any light upon the subject, I have something to do with standard measures, but remarks upon that subject would hardly be speaking to the question.

To make use of a national standard would, in some parts of the world, increase the value of machinery ten per cent. In Sweden, for example, machinery not made to standard sizes would be reduced ten per cent. in value. I think the same is true in South and Central America, but am not so certain about it there. The commercial phase of this question is of particular importance. As to the mechanical part, there are none better able to discuss it than the Technical Society; not only a few, but a great number of its members. Perhaps Mr. Dickie will favor us with a statement of the facts as they exist."

MR. DICKIE.—"There are some things in regard to measures that are not standard that can be explained. For instance, an inch board is seven eighths of an inch thick, and a two-inch board is one and three fourth inches thick. The reason of this seems to be that the person who cuts up the timber expects to get so much out of it, and adjusts the sizes accordingly.

In regard to iron work the same rule prevails. Shafting has been made, as a rule in San Francisco, from merchant bars, and each shop, I believe, has a different gauge for shafting, and these are in a large degree dependent upon the opinions of the foreman of the shop.

Sometimes the standard has to be changed for shafting. I remember, eighteen years ago, of a very large shipment of bars for shafting from England to San Francisco, none of them would turn up to the gauges, and the gauges had to be made to suit the shafts. So it has gone on until we find that each shop has a sort of independent practice which prevails in these matters.

Why it continues now is a mystery; there is no necessity for it whatever. It is a source of infinite trouble, annoyance and confusion. Suppose that a Mexican firm sends here for a certain size of shafts, and they are sent there, and they are not to standard size, there is trouble about it. I think our company has a good many tons of shafting in Mexico that has never been paid for, because not of the size ordered.

If the manufacturers would come together in a right spirit, they could regulate this matter. The great difficulty is that if one shop adopts a standard, the other shops adopt something else; they are enemies to each other, and they are apt to injure each other whenever they can. There is an opinion that if you send out machinery that nobody else can fit parts to, it will come back to the same shop for repairs.

Except for shafting, and round work generally, I believe there is a sort of gauge system. Unfortunately, each shop has its own. Until the proprietors get closer to each other, and will consult pleasantly about matters in general, there is no help for us. The only way by which this can be brought about is a better feeling among the manufacturers. A society like ours can not dictate to them, or influence them very much to make their work of the same size. Until San Francisco gets out of her provincial ways, in more things than one, we will have to continue as we have been doing. Everything is governed here by "certain powers," not amenable to technical influences.

Then again, as long as customers will accept a false shop gauge, and irregular dimensions without demurring, and as long as they are satisfied with machines that fulfill their purposes without any reference to standard gauges or sizes, that long the present system will go on. There are but two ways by which change can be brought about, either the customers must insist upon certain rules and regulations in regard to gauges, or else proprietors of establishments that manufacture machinery must get together, compare notes, and establish something in common that all will receive."

MR. BEHR.—"How do you manage in your own work?"

A.—"In shafting, for example, I get the actual size of the shaft. The Eastern manufacturers advertise their shafting, and give the actual size to which it is turned, and do not state that a shaft is three inches which is actually two and seven eighths."

Q.—"Do you figure the decimal foot and inch on your work?"

A.—"No. I use the English system of measures, inasmuch as we have not the metric system in use."

MR. VISCHER.—"To what extent does variation of sizes exist in the shops?"

A.—"A three-inch shaft would not fit a hole bored in another shop. It would depend upon what shop it came from; but roughly speaking, perhaps by as much as one sixteenth of an inch."

Q.—"What uniformity would you expect in work of a specific size, coming from the same shop? Does that also have to do with the matter? If a uniform system were adopted would not the work itself be better and more accurate?"

A.—"In most of the shops a uniform system is adopted, so far as shafting is concerned; that is, they adhere to their size. They have gauges for shafting, and a shaft is finished to these sizes. A pulley ordered from the same shop would fit."

Q.—"There is no economic reason why a uniform standard should not be adopted, is there? Would a gauge suitable to one shop be equally as suitable to another as far as the two are concerned?"

A.—"Yes. But arbitrary gauges should not be adopted; that is, standard sizes should always be adhered to. Nowhere is there any strict adherence to gauges where heavy machinery is involved; it would not be possible. For instance, in the reaming of a very long hole for bolts and connecting rod; bolts, say three and one half feet in length, it will often occur that one of these holes has to be reamed slightly larger than the others, and it is absolutely necessary

in order to bring things together. While the specifications might require that these things should be interchangeable, they are not strictly so made."

Q.—"At the same time the case you are stating now is not one of those which lies within the scope of your first remarks?"

A.—"No. In the matter of shafting, and round forms generally, as they are used, and turned work, there is no reason why standard gauges should not be used. There need be no arbitrary sizes; the standard gauge should be used as it is used for threads."

Q.—"To what extent is the more uniform practice carried out in the East?"

A.—"The gauge system prevails quite generally among manufacturers of machines. It is not used so much in regard to the manufacture of engines as of machines. In machines used in textile manufactures, for instance, a gauge system is absolutely necessary. If we on the Pacific Coast should manufacture such machinery gauges will be *forced* into the machine shops. I doubt whether the gauge system is carried out so perfectly in this country as in Europe. Mr. Richards knows better than I in regard to that. I know that in flax machinery a change wheel coming from almost any of the European works would take its place on any machine that had been made within the last fifty years, and fit perfectly. It is a great advantage to have it that way. I think the interchangeable system is nowhere carried out as it is in that branch. For spinning long flax there are gear wheels extending up to hundreds, and you may take a frame made in Leeds, and a frame made in Scotland, and, I think, also in France, and the same change wheel can be used on all of them.

The system of gear wheel making, too, is much more perfect there; not wheels that are cut, but those that are cast. I think one could give an order to Chambers for change wheels made by his machines to fit on a machine made by any other firm within a range of fifty years, and when received, it would fit in its place."

MR. RICHARDS.—"They do not make wheels in common foundries in England; that is a wheelmaker's special business."

MR. BEHR.—"Are all the calendered shafts made to the same gauge?"

A.—"They are made to a standard gauge, and very accurately."

Q.—"Do all manufacturers in England agree on the same standard?"

A.—"Yes. It is a national standard gauge."

MR. VISCHER.—"Are you able to tell us through what agency the uniformity that exists in Europe was brought about?"

MR. DICKIE.—"I think, perhaps, through the agency of half a dozen of the earlier mechanics about the beginning of this century who established gauges, and were persistent in maintaining and preserving them. Perhaps Whitworth has had more to do in establishing gauges for England than any other man. Before his time I think Clement was the first to work systematically with gauges."

Q.—"In the early days of engineering in the United States were there not American manufacturers who used their efforts in that direction—Sellers, for instance?"

A.—"That was at a later date. Although Sellers has always had gauges of his own. I don't think he has ever made any effort to make gauges that would be generally applicable to the work of the country."

Q.—"Was not his influence sufficient to make other manufacturers adopt his gauges?"

A,—"No. The Sellers' thread has not been adopted."

MR. RICHARDS.—"The American Standard Gauge Works, in Wilmington, have produced more gauges than any other firm in this country, but have not written about it so much. The gauges supplied exceed one hundred thousand."

MR. DICKIE.—"In regard to measuring by touch, has there been any other method used in shops as practical?"

MR. RICHARDS.—"I think measuring by sight is only a laboratory process. I am so prejudiced about it that I am almost afraid to make any remarks. I dislike the whole scheme of visual readings. A machine has been made by Sir Joseph Whitworth by which the one millionth part of an inch can be ascertained. A visual reading cannot do that. In my opinion it is impracticable, except as a laboratory method. I am speaking strongly so as to provoke discussion."

MR. SWAIN.—"Watch factories are using, almost exclusively, the sight gauges."

MR. DICKIE.—"There is one difficulty about measuring by any kind of visual reading. Most any workman or mechanic can understand touch—he can feel, but it is a different matter when it comes to perception by sight; there is always the liability of mistake by reading a scale wrong; it requires some education. But a lathe man who is accustomed to calipering, can feel with wonderful accuracy; some are exceedingly expert. Now, for instance, we put liners into

steam cylinders, and have to determine the fit required to put one in a cylinder under 80 tons pressure; we have our lathe men who can do this, and it will fit precisely in its place. That requires measurement that no sight reading that I can conceive of, would accomplish."

MR. SWAIN.—It seems to me that one reason why western cities have failed to have a standard is because drills and reamers, and all standard tools used to do the work have been available in the Eastern States; but if a western shop wants to fit a piece of work the first thing done is to drill a hole and fit a piece into the hole. They go into the blacksmith's shop and have a drill hammered out to the nearest size that can be got from the scale, sometimes it is turned and sometimes ground on a stone, to fit the work ready to drill. But in the Eastern States you can go into a store and get standard drills and reamers. They have a better chance to attain standard work. It seems that a set of gauges are useless in a shop without having the means and tools also to do the work. In Palmer & Rey's shop we are using, almost exclusively, Richard's standard gauges, and we find them very satisfactory. We are using them in conjunction with the Morse reamers."

Q.—"In the armories, do they follow the standard gauge in minute measures?"

A.—"I think the original standard was obtained from Whitworth & Co., and duplicates made of varying degrees of accuracy. The cheaper ones were given out around the shop, while the better ones were kept in the different departments of the main office, and in the fitting of the gun parts every foreman has two gauges. One is an allowance for error, the other a small one, and the piece of work must be fitted so that it will not go through the small gauge, but must go through the larger one. In that kind of work a certain amount of error must necessarily be allowed, although the error in gun work is very slight because the pieces are small. As they increase in size the difficulty of duplicating is very much greater. Although one can have a standard gauge for boring a cylinder or anything else, it is difficult to keep a tool of such size that it will duplicate any number of them and keep absolutely to that standard."

The Elgin Watch Factory uses the metric system and sight gauges entirely, they are not dependent upon the condition of the workmen, that is, whether a man feels well or not in the morning. The difficulty of calipering a piece of work is this, the same man will caliper differently at different times. The sense of

feeling varies. I think two cylinders held up to the light will show almost as fine an error by sight as can be found through the sense of touch."

MR. WOOD.—"I am not in the ranks of mechanical engineers, I am only a contractor. Still I have a profound appreciation for their work. Societies in the east, analogous to the Technical Society, have done a good deal toward establishing uniformity in some lines of work, and I do not see why they should not accomplish something in that direction. I believe it would be well for the officers of this Society to prepare a circular, worded in the technical lore of Mr. Dickie or Mr. Richards, or a committee including those members, and have these circulars distributed among the various shops in the city and among those directly interested in this matter, so as to get an expression of opinion from them, and the arguments from their point of view. I do not see why this Technical Society is not competent to draw their fire and to agitate the subject, and to keep it up until some uniformity is secured. I will say, as a representative of a contracting firm, that I would welcome most gladly a uniform standard in any work. Now, we have hardly a uniform standard in anything."

MR. DOW.—"Unfortunately I am one of those manufacturers who have so many different gauges to contend with, or rather I did have them some six or seven years ago, so that I found it necessary to take a positive standard. I used the Brown & Sharpe system of gauges for all diameters up to 24 inches. I must say that in my own works I do not suffer any inconvenience. But I know, in general, the shops in this City do not do their work on the gauge system, and as a general rule such a system is very badly needed. I think the only plan is to do as Mr. Dickie says, get the proprietors together and work in harmony and good feeling."

MR. RICHARDS.—"There has been very little said about the economical part of the problem, the saving that may be effected by this system. I don't know that anybody is prepared to give any statistics about it, only by general observation. There is an economical problem lying at the bottom, in the matter of tools and cost of doing work."

MR. DICKIE.—"It is not so much in obtaining gauges and having them, as in the working thereof. Little mistakes are made and rectified, and machines go out without any record of these corrections, that makes a great deal of trouble—a thing is supposed to be

made to a gauge when it is not. I believe that gauges in many kinds of work can make a saving of at least 60 per cent."

MR. BEHR.—"Mr. Richards spoke about machines manufactured for South America, and if made to a standard would sell more readily. I suppose it would be necessary to use the metric system, as in France and Germany, and all European countries where this system is used."

MR. DICKIE.—"All the work we have got from Krupp has the Whitworth threads, unless specially ordered otherwise. I noticed that the French specifications all call for Whitworth threads. In some work that we procured for the *San Francisco* we had to renew the screws after they were received here. So we are just as badly off with the work of other people as other people are with our own."

MR. RICHARDS.—"I was not aware that the English standard is used in France and Germany for threads. I suppose it is done for commercial expediency. In places like South America and distant parts of the world, the English have gone there first, and the measures generally had to conform to their standards."

REGULAR MEETING, FEBRUARY 5th, 1892.

PROCEEDINGS.

MINUTES.

The meeting was called to order at 8:30 P. M., by Mr. C. E. Grunsky, Chairman.

The minutes of the last regular meeting and of the annual meeting were read and approved.

The following new members, having been balloted for, were declared elected:

Theodore Wetzel, Supt. Derbec Mine.....North Bloomfield, Cal.
L. C. Russel, Mechanical Engineer.....San Francisco, "
Frank H. Olmstead, Civil Engineer.....Riverside, "
Geo. P. Cramer, Surveyor, (Junior).....Seattle, Wash.
J. F. Morrow, Surveyor, (Junior).....San Francisco, Cal.

The following names were proposed for membership and referred to the Board of Directors:

Bernard Bienenfeld, Civil Engineer, of San Francisco; proposed by Ross E. Browne, Frank Soulé, and Hermann Kower.

Conrad Eimbeck, Civil Engineer, of Guaymas, Mexico; proposed by Hubert Vischer, Luther Wagoner and Carl Stetefeldt.

D. C. Henny, Civil Engineer, of San Francisco; proposed by Hubert Vischer, Geo. F. Schild and John Richards.

Alexander M. Reynolds, Civil Engineer, of Seattle, Washington; proposed by J. P. F. Kuhlmann, H. C. Behr and Otto von Geldern.

Arthur H. Sanborn, Ass't City Surveyor, San Francisco, proposed by H. D. Gates, Otto von Geldern and Geo. F. Schild.

Mr. N. S. Keith invited the members to visit his place of business to inspect a new electric drill. He stated that the time between 10 and 11 A. M. would be most suitable, during the coming week.

A communication from Mr. Luther Wagoner was read, in which he donated to the Society a complete set of Van Nostrand's *Engineering Magazine*, consisting of thirty-four bound volumes, and expressing the hope that similar donations would also be made by all who have the Society's welfare at heart.

The Secretary was instructed to communicate with Mr. Wagoner, and to express the appreciation of the members for this valuable gift.

Mr. D. C. Henny, Civil Engineer, then read an interesting paper, treating of "Water Pipes built of Wooden Staves," a subject comparatively new to the profession, which caused considerable discussion, entered into by a number of prominent members.

Two visitors, Prof. Marx, of the Leland Stanford, Jr. University, and Professor Kernot, of the University of Melbourne, Australia, also spoke briefly on the same subject.

(This paper, with its discussion, will be published in the next number of the Transactions.)

DISCUSSION OF TOPICAL QUESTIONS.

The topical question submitted for discussion was announced by the Chairman:

What is the effect of wind on the mean velocity of a river?

The Secretary then read the following communication from the author, Mr. D. E. Hughes, in order to incite general interest in the subject:

CONCERNING SURFACE SLOPE OF WATER, DUE TO WIND; AND THE EFFECT OF IT ON THE MEAN VELOCITY OF A STREAM.

Not till after this question was proposed did the writer learn that anything would be required of him, or something easier would have been sought; yet, in preference to retreating, this paper is offered, with the sole plea, however, that it may provoke discussion.

Wind imparts to water a nearly horizontal force, which, taken with gravity, furnishes a resultant out of plumb, thus causing a surface slope. This wind force is due to what, for want of a better name, is called fluid friction, and to a component of wind pressure on an oblique plane. This plane is furnished in the windward side of waves, by the inclination that the surface of the water has already attained, and, maybe, by virtue of a dip of the wind.

Fluid friction and wind pressure are both quite generally assumed to vary as the square of the velocity (v^2). Gravity on a column of water varies as the depth (d). If nothing more were taken into consideration, it would appear that the slope equals $k \frac{v^2}{d}$ where k is a constant.

Wind acts more on the upper portion of a body of water than it does lower down. In consequence of this, is there, in addition to the undertow of the waves, any under-current windward caused by super-elevation of the general surface at the leeward side? If so, then the above expression for slope must be diminished by what? Probably some function of depth, and velocity of the wind.

The writer does not deny that there is an underflow due to the existing differences of head, or, rather, to a tendency to a still greater difference; but he thinks, without much investigation, however, that

in case of shallow water, where viscosity and bed resistance are relatively great, the negative quantity, occasioned by the undercurrent, is small in comparison with the positive term, and, since wind slopes on water of considerable depths are trifling anyway, the opinion follows, that for most practical purposes the simpler formula will be sufficiently correct, if it is adjusted to water 4 feet deep and wind of 40 miles.

The coefficient required for this must be supplied from observation. An approximate one is deduced from the following imperfect data.

In the southern part of the *Colusa Basin*, which is a depression flanking the right bank of the Sacramento River, north of Grafton, there is an area about 9 miles long, which is very nearly level lengthwise, and practically bounded at the ends by levees. Its direction is that of the south wind, and "northers," which come there from a little east of south and west of north, respectively.

Last winter it was observed that a strong south wind raised the general surface of the water at the north end 6 inches on a stake some distance from the levee where the water, on a still day, was 4 feet deep.

The ground being level, the slope lengthwise of the trough was probably not quite uniform owing to change in depth caused by the slope, but the excess in the half where the depth of the water was diminished so nearly atoned the defect in the other half that the average for the whole was practically the same as that obtaining at the center, where the depth of 4 feet was not altered. The width of the water, averaging more than 3 miles, was not uniform; but its figure was so nearly symmetrical, with respect to the mid-cross-section, that the depression of the surface at one end is assumed equal to the elevation at the other, or 6 inches, making a total fall of one foot in the length of 9 miles.

I do not know what the velocity of the wind was, but make the assumption (and the constant is at the mercy of it) that it was 40 miles per hour.

The levee on the north end of the 9-mile trough does not extend clear across, but turns to a northerly direction, leaving a channel west of it. Up this channel about 1½ miles, where the ground is a half-foot higher, another observer noted as follows: "Depth in calm a little less than four feet; surface depressed by strong north wind, 8 inches."

It may be noticed that the slope found, will, when reversed and extended 1½ miles, just fit this case.

These observations were not made with a view to their technical value, but are, nevertheless, trustworthy as far as they go.

I think that a little of that slope was borrowed from the tendency to a greater one in the shallower water along the sides, and that if the 4-foot water had been kept separate from the rest by parallel levees, the surface fall between them would not have exceeded one-tenth foot per mile. Putting this in the formula it becomes:

$$\text{Fall in feet per mile} = \frac{(\text{Velocity of wind in miles per hour.})^2}{4{,}000 \text{ times the depth in feet.}}$$

As before mentioned, this rule, even if the above data were correct, is right only for a 4-foot water and a 40-mile wind. For a less depth it does not give quite enough, while for deeper water it shows too much.

It is desirable that much and varied data on this point be obtained, not only to test this coefficient, but in order that the elements of a better formula may appear. This rule indicates that the *slope* of ordinary rivers is not appreciably affected by wind, while water 6 inches deep may be driven entirely out of a pond by a not very uncommon wind, if the bordering ground rises not faster than 8 inches to the mile; and that a stream 2 feet deep, falling 2½ inches per mile, will be stopped by a 40-mile wind, unless its feeder can furnish it more head.

Now suppose a canal 4 feet deep with a fall of 0.4 feet per mile, and a 40-mile head wind. How shall we calculate velocity? Will it be proper to simply reduce the 0.4 fall to 0.3, and use that as though no wind were blowing; or should we calculate velocity due to 0.4 then to 0.1, and take the difference; or may we suppose the wet perimeter to extend clear around, thus diminishing the hydraulic radius, and use some averge coefficient, if so, what slope must we take, 0.3, 0.4, or 0.5; or must the problem be approached from an entirely different standpoint?

The last paragraph above is inserted only to enumerate the plans that may suggest themselves before the proper one is determined upon.

The Chairman stated that this question would remain open for discussion, and that communications from any one in the Society were invited in order to examine into a subject that promises to be of considerable interest. He hoped that it would be brought up again in the near future, and advised the circulation of Mr. Hughes' statements among the members.

Adjourned. OTTO VON GELDERN, *Secretary*.

TECHNICAL SOCIETY OF THE PACIFIC COAST.

SAN FRANCISCO, CALIFORNIA.

INSTITUTED APRIL, 1884.

TRANSACTIONS.

(VOLUME IX. No. 2.)

NOTE.—This Society is not responsible, as a body, for the statements and opinions advanced in any of its contributed publications.

WATER PIPES BUILT OF WOODEN STAVES.

BY D. C. HENNY, MEM. TECH. SOC.

[Read Feb. 5, 1892.]

Wooden stave pipe has been so largely used in some of our western states, notably Colorado, for carrying water for domestic supply and irrigation, that it is surprising to find this kind of pipe comparatively little known in California.

The title of this paper indicates my intention not to discuss wooden pipe in general, and if I refer to bored log pipe here, it is because experience with it extends over a longer period, although the use of wooden stave pipe is by no means new. That a century and less ago hundreds of miles of bored pipes have been used in England and in some of our eastern cities, before there was a demand for high domestic pressures, is well known. But what is perhaps not so generally understood, is that their abandonment has not been due to any supposed or real unfitness of clear sound wood as a water carrier, but to mechanical causes, involving both its strength and its cost. And it is for this reason that their use has been resumed, in such shape and with such improved methods of manufacture, as to make it meet the requirements of the present time.

The remarkable lasting qualities of wood, when constantly under water are well understood. A wooden pipe filled with water, under pressure is, as far as the wood is concerned, in the same condition as if it were submerged, even though the soil in which it lies be

perfectly dry; provided of course that the thickness of the wood is not excessive, so that the water can penetrate it for its full thickness and thus maintain a condition of complete saturation. The experience with bored log pipe demonstrates this fact. Numerous are the instances of bored logs, dug up after many years of service, and all such pipes were sound when taken up, unless they had been suffered to remain in the ground long after they had been abandoned.

The principal qualities which material for pipe should possess are water-tightness, smoothness of interior surface, and durability; great strength is not necessarily one of them, for although the strength to resist inside pressure may be vested in the material of the shell itself, as in uncoated iron and steel pipe, it may also be concentrated upon the outside surface, or spread around it, and thus be kept from contact with the water. In fact, when we consider the great care exercised in coating iron and steel pipe it is apparent that the coating forms the real shell, the material back of it simply serving to support it. This is especially evident in the cement lined pipe, which has been much used in the East, the cement having no strength of its own against bursting. The necessity of coating iron and steel pipe is, of course, due to their being short lived materials when in contact with the water, and for this reason undesirable for pipe shell in the sense the word is here used, although eminently fit to support it. Use wooden staves instead of asphalt varnish for a shell, concentrate your metal in the most advantageous form around it, and you have the wooden pipe of which I am to speak. I do not mean to imply, however, that in this manner the stave pipe was evolved in practice, for it has too close an analogy with the ordinary water tank and barrel to doubt that these were its real progenitors.

DESCRIPTION OF PIPE.

This pipe may be considered an indefinitely extended horizontal cylindrical tank. The staves are dressed like tank staves, the flat sides to the cylindrical surfaces conforming to the inside and outside diameter of the pipe, the edges to radial lines. Some pipes have been built with slightly V shaped edges, male on one side, and female on the other, which offers some advantages in its construction, but does not give as firm a bearing of one stave upon the other. Thus far the pipe and the water tank are exactly alike. The difference enters with the necessity, with pipe, of joining the butt ends of the staves. Joints are generally weak places in all pipe, and it is an advantage with this pipe, that the staves can be

made to break joint so that this weakness may not occur at the same point, but be distributed along its length; in this manner the pipe becomes one continuous stiff tube, with no tendency to settle in one place more than in another. To find a sure and simple method to make the butt connections tight under pressure, Mr. C. P. Allen, some nine years ago, while chief engineer of the Denver Water Company, being called upon to construct a 48-inch pipe line for his company, instituted a series of experiments, the results of which he finally patented. It is under this patent that most of this pipe has been built.

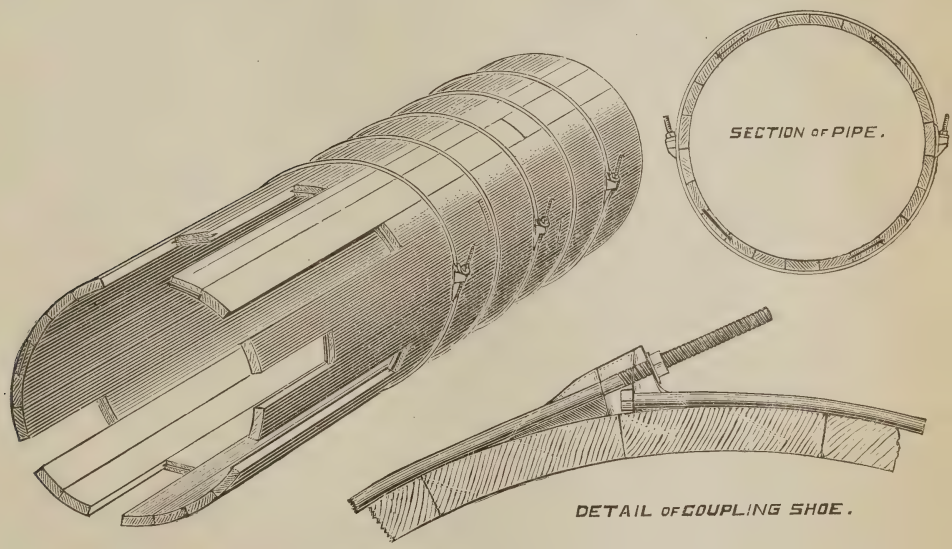

FIG. 1.

His experiments covered both the best butt joint and the most practical form of bands and shoes. The ordinary tongue and groove was tried, and so were other simple wood connections. Whether it was due to the difficulty of cutting and preserving the sharpness of all corners and edges; whether to slight imperfections of the wood at the ends of the staves, such as small shakes and cracks; to a greater deflection under pressure of the stave at the joint, than of the adjoining stave where no joint occurs, or to other causes; the pipe showed an aptness to leak at the intersection of the seam and butt joints, in other words, at the corners of the staves. It was not until the simple device of

inserting a piece of band iron in the end of the stave was resorted to, that the problem was satisfactorily solved. As it is now used, the plate is usually cut of No. 12 band iron, one and one half inches in width. The stave is slotted in the ends to receive these plates, as shown in Fig. 2.

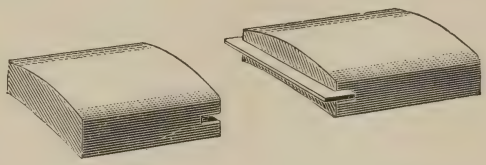

FIG. 2. VIEW OF BUTT JOINT.

Now imagine a joint without the plate; the space left for it is smaller in all directions than the plate itself. It is less wide than the thickness of the plate, so it fits snug, and the edges of the plate penetrate the wood, sidewise in the bottom of the slot, and endwise in the side of the adjoining staves. It carries the contact of stave against stave, as far as water tightness is concerned, back ¾ of an inch from the end of the stave, thus neutralizing the effects of such imperfections in the wood as do not extend further than the depth of the slot, and secures an equal deflection of the stave, at the butt, and of the adjoining staves. The stave is thus square at the ends, having no projecting corners which can be easily damaged. And although the staves are slotted at the mill, it is no slight advantage that this slotting can be easily done with a common hand saw on the work, in case staves are cut.

The thickness of the stave depends upon the pressure of the water, the size of the pipe and the load upon it. The thickness required for various pressures must be determined by experiment. I know from experience that redwood of a thickness of 1⅜ inch shows no sign of the water oozing through under a pressure of 165 feet, and I am inclined to the opinion, seeing that every annular ring in redwood contains a very hard, flinty shell, of which there are some 20 or 25 to the inch, that that thickness will prove tight under much higher pressure. The diameter of the pipe and the superincumbent load determine the thickness of the staves, which act as an arch to support the load.

In attempting to calculate the required thickness of the wood for various diameters and top loads, we meet with the obstacle that the initial compressive strain in the wood, caused by the tightening of the bands, being one of the main factors, is rather uncertain and

hard to determine, varying along the length of the pipe with the number of bands, and with the degree of swelling of the wood; I therefore take experience and experiments to be a safer guide.

The first wooden pipe built in Denver was 48 inches in diameter, and the staves were cut from 2-inch lumber, running about 1⅝ inch in thickness. Where this pipe was laid in good material it preserved its circular section, but part of it was laid in soft muck, and there the pipe became somewhat elliptical, in some places, with the long axis horizontal, in others vertical, as the loads on top or those on the sides were in excess. By dumping slag from the smelters, either alongside or over the pipe, it was restored to its original shape without trouble. This shows that here the safe limit for 2-inch timber was nearly reached for pipes which are to be covered two or three feet.

A 72-inch pipe was built on the Maxwell grant, in New Mexico, of 3-inch lumber, running about 2½ inches after dressing, and no flattening was observed.

The banding of the pipe is done in a manner similar to tanks, except that instead of flat iron bands, round steel is used. Herein lies the main difference between the stave pipes which have for years past been built in the East, and those which have during the last eight years been constructed in the West.

A pipe line, that at the time attracted considerable attention, was built by Mr. Fanning, for the water works at Manchester, New Hampshire, for water power purposes. It is six feet in diameter, banded with flat iron, and Mr. Fanning writes that it is in good condition. It was built in 1874, and is described in his treatise on water supply engineering.

The round form of bands is advantageous in as much as the life of the pipe is that of its shortest lived parts, which are the bands, although it is of course possible to replace old bands by new ones without abandoning the timber shell. Now the circle has a maximum area with a minimum of circumference, and thus offers the least possible surface to corrosive influences. Besides, the round form offers special facilities for joining the ends so they can be tightened with a single nut.

The question may be asked: why, if round bands are economical on pipe, they are not commonly used on tanks? This is due to the tapering shape of tanks, which allows the bands to be cut to exact lengths and riveted, and to be driven down from the narrow top of the tank without any other arrangement for tightening, the

same as with barrels. It cannot be denied that a flat band has a better bearing on the wood than a round one, but that this larger bearing is entirely superfluous, I will endeavor to show further on.

These rods are, before being bent, simple straight bolts, with a head at one end and a thread and nut at the other, in length from three to five inches longer than the outside circumference of the pipe. They are bent on the work on bending tables, and then dipped in mineral paint or asphalt varnish, and hung up to dry several days ahead of the work of pipe laying. For large pipes two segmental bands are used, the rods otherwise becoming too long and heavy for easy handling.

The ends of these rods are joined together by means of a cast iron shoe, or saddle, of a simple form — several forms being in use. They are all shaped to fit the outside surface of the pipe for which they are designed. In each there is a shoulder for the head and a shoulder for the nut, the threaded end being made to lie over the head. Thus the strains on the shoe are not only as much as possible compressive strains, but they are all through the center line of the shoe, producing no tendency to twist, as is, for instance, the case with a casting in which the ends of the bands lie alongside each other. These castings can all be made at a low price per pound, there being no machine work about them.

CALCULATION OF STRENGTH.

To properly decide upon the diameter and spacing of the bands, we must understand the exact purposes for which they are put on. On a grade line pipe they serve the purpose of holding the staves together and securing the rigidity of the pipe and the tightness of the seam joints. There is an initial strain on the band when tightened, equal to the compressive strain in the wood. This strain is increased as the wood swells, when water is let into the pipe. The additional strain due to this cause, however, can never attain great proportions, as it increases very gradually, and is kept in check by the simultaneous adjustment of the fibre under the band. Finally, there is a strain on the band caused by the weight of the water from top to bottom of section, which may amount to about 16 pounds for 12-inch, and 2,074 pounds for 10 feet pipe, per lineal foot of pipe. Of all these strains, the one produced by the cinching of the bands is most important. In some cases the bands were spaced 18 inches apart with satisfactory results, on pipe under light heads.

For a pressure pipe we have to consider the bursting strain. No matter whether the shell be a mere coating of tar or asphalt, or a

lining of cement, or wooden staves, a certain area of iron or steel is required on the outside to resist these strains, and in the case of wooden pipe it remains to so divide it over bands of the right diameter, that the staves may receive support with sufficient frequency to prevent excessive deflection between the bands, and excessive indentation at the bands.

The distance between the bands for bursting strain is expressed by the following formula :

(1.) $$l = \frac{2\,S}{d\,P}$$

l being the distance from center to center of band in inches.
S " the admissible strain on the band in pounds.
d " the inside diameter of the pipe in inches, and
P " the pressure of the water in pounds per square inch.

The distance between the bands, which keeps deflection of the stave at its weakest point (that is the butt joint) within $\frac{1}{1000}$ part of the span from band to band, is :

$$L = \frac{25.6\,h}{\sqrt[3]{P}}$$

h being the thickness of the stave in inches. Therefore, the condition imposed by the deflecting of the stave is :

(2.) $$l < \frac{25.6\,h}{\sqrt[3]{P}}$$

I give this formula rather to show the relation between distance of bands, water pressure, and thickness of stave, than that I would unreservedly recommend it for use. While it is based on a modulus of elasticity in relation to bending of 1,600,000—as given by Weisbach for wood, generally, which may be too high in the case of redwood—on the other hand, the limit of $\frac{1}{1000}$, the span for permissible deflection, is arbitrary. Experience has so far shown that where seam leaks have been found, they were clearly due to imperfect lumber, imperfect milling, damage to the stave in handling, or insufficient cinching of the bands, and not to excessive distance between the bands.

To a possible crushing of the fibre under the band, I have already referred. Redwood is but slightly indented under a pressure of 1,000 pounds per square inch, and I find that a rod may sink into the wood so as to get a bearing of 60° along its circumference, indenting the wood to a width equal to its radius, without perceptible damage to its fibre. The safe resistance of the bands against the

staves thus being proportional to the diameter of the band, and the strength of the band being approximately proportional to the *square* of the diameter, it follows that if the required strength of the steel is distributed over four bands of one half the diameter, instead of being concentrated in one band of the full diameter, the safe resistance of bands against staves will be twice as large. Thus we can, by a proper subdivision, provide sufficient bearing for the staves. $\pi(d + 2h)$ being the outside circumference of the pipe, and r being the radius of the rod, it follows that $\pi(d + 2h)\, r \times 1{,}000$ equals the safe resistance, in pounds, of the bands against the staves. The pressure of the water against the staves is $\pi\, d\, P l$, therefore,

$$1000\, \pi\, (d + 2h)\, r > \pi\, d\, P l, \text{ or}$$

$$l < \frac{1000\, (d + 2h)\, r}{P d}$$

or substituting for l the value in formula (1)—

$$(3) \qquad S < 500\, (d + 2h)\, r$$

That this condition is readily complied with, is evidenced by the following instances:

$$d = 12 \qquad h = 1\tfrac{3}{8} \qquad r = \tfrac{3}{16}$$

$$S < 1383$$

S being 1143 pounds for $\frac{3}{8}$-inch rods, figured in the thread, with a factor of safety of 4.

$$d = 20 \qquad h = 1\tfrac{1}{2} \qquad r = \tfrac{1}{4}$$

$$S < 2875$$

S being 1960 pounds for $\frac{1}{2}$-inch rods, figured in the thread, with a factor of safety of 4.

$$d = 54 \qquad h = 2\tfrac{1}{2} \qquad r = \tfrac{5}{16}$$

$$S < 9219$$

S being 4600 pounds for $\frac{5}{8}$-inch rods, upset to $\frac{7}{8}$ inch, and figured in the bolt with a factor of safety of 4.

This shows that flat bands offer no advantage over round bands so far as indentation is concerned, since the larger bearing they provide is superfluous.

MATERIALS.

The bands used are of mild steel with an ultimate strength of 70,000 pounds to the square inch for ⅜-inch rods, 65,000 pounds for ½-inch rods, and 60,000 pounds for larger diameters. When the rod is not upset, as is the case with the smaller diameters, we must figure the strength of the rod in the thread; and, it should be borne in mind, that since the strongest part of the steel lies on the surface, and is cut away by the die, the average strength of the remaining material is less than that of the full rod. I therefore deduct from the strength per square inch, in the case of ⅜-inch and ½-inch rods 10 per cent., and for larger sizes 5 per cent. Thus we get for the strength of bolt, in the thread, per square inch:

⅜ inch	63,000 pounds
½ "	58,500 "
Larger Sizes	57,000 "

The wood that has been used in the pipe lines in Colorado is redwood, Texas pine, and, in some instances, native lumber. In drawing up specifications for cast iron pipe the engineer calls for the best material, and does not admit blow holes, flaws, or other imperfections. There is no reason why the same care should not be exercised with wood; only well seasoned and perfectly clear, close and straight grained lumber, free from pitch, and with as little liability to swell and shrink as may be, should be specified. And there is no other, among the soft woods, that comes up to these requirements so well as redwood does; a fact which is beginning to be appreciated even in Colorado, where this kind of wood, owing to high freight charges, is quite expensive, the difference in price as compared with Texas pine being no less than $15 per thousand.

It needs no arguing that the lumber should be milled with the greatest exactness, both as regards the section of the stave and its ends. The lumber should be shipped in box cars, and at the point of destination should be piled up and covered, and not strung out along the trench until ready for immediate use.

The saddles or shoes should be of the best grade of cast iron, free from flaws, blow holes, or other imperfections. They should be rattled in a rumbler until they are bright and free from sharp edges, splints and tags.

MANNER OF CONSTRUCTION.

The erection of wooden pipe requires skillful and patient labor. The work proceeds about as follows:

U shaped, outside forms, usually of bent gas pipe, are put on two-inch blocks, and in these are laid the staves forming the lower

half of the pipe. Then inside forms are put in position, on which are placed the balance of the staves, completing the circle. The staves are so placed that the end of one stave projects beyond, or falls back, 18 or 24 inches from the ends of the adjoining staves, so that the end of the pipe, during construction, presents a jagged appearance.

The bands are then put on and tightened, whilst the pipe is rounded out. After all bands are put in place at the proper distances and are securely cinched, this first section of pipe is ready to be extended in both directions.

The clips or metallic tongues are put in the slots, and the staves of the next section are put in place the same as before. The bands are put on, and whilst they are being tightened the staves are driven up with a heavy sledge and driving stick. The pipe builders are followed by back cinchers who give the final cinch to the bands. If the pipe is built in the trench, they in turn are followed by back fillers who tamp the earth under and alongside the pipe, and cover it. In this way one gang builds from 75 to 175 feet per day. On long pipe lines a number of gangs are put to work, and where they meet a buckle is made, by fitting the staves and springing them in. Connection with cast iron pipe or gates is made by means of special spigot and bell pieces, having large and deep bells into which the wooden pipe enters. The space between pipe and bell is caulked with oakum, or run with lead and caulked.

There should be air and check valves when there are summits on the pipe line for the emission and admission of air. The nipples for these valves are screwed in a hole in the wood, bored with a smooth cutting bit or auger. It is well to use lock nuts and oakum packing in connection with these nipples, although not necessary. Ordinary corporation cocks for taps may be screwed in, in the same manner.

For short irrigation siphons it is important, in order to save loss of head, that the entrance be made easy, and it is a very simple matter to give the end of the pipe a funnel shape, by inserting between the regular number of staves others planed down to a point.

It is suprising how easily this pipe can be made to follow, in a general way, the undulations of the ground, although the curvature to which it can be laid is, of course, limited. Thirty inch pipe readily follows curves of a radius of 250 feet.

CARRYING CAPACITY.

To my knowledge no accurate measurements have been made of the carrying capacity of wooden-stave pipe. I use the Kutter form-

ula, putting the coëfficient of roughness n at 0.010, which Kutter, for open flumes of well dressed timber, states to be 0.009. Since it presents no joints or rivet heads to the current, and is otherwise perfectly smooth, it is plain that its carrying capacity must be greater than that of sheet iron or steel pipe, and that it greatly exceeds that of cast iron pipe. The inside remains smooth and clean, and there need be no fear of the capacity gradually diminishing.

COST.

The cost of this pipe is in the nature of the case closely dependent upon the pressure. Graphically we can represent the connection between cost and pressure, both for wooden and sheet-iron pipe, as shown in Fig. 3.

These diagrams have not been drawn to any scale or for any special size pipe, but are merely intended to illustrate the characteristic increase of cost with increase of pressure for each kind of pipe. It is plain that the shaded triangles represent cost of material required over that which is called for by the bursting strain for purposes of stiffness and rigidity. Although wooden pipe under high pressure may require as much, or even more metal than sheet-iron pipe, the reverse is the case with low pressure, as is still further shown in the following table:

Diameter Pipe.	WOODEN PIPE.			SHEET-IRON PIPE.		
	Diameter Bands.	Weight Metal	Safe Pressure. Factor of Safety 4.	Gauge Iron	Weight Metal.	Safe Pres're. Working Strain 10,000 lbs.
		Bands every 12 inches				
12	⅜ inch Straight.	2.5 lbs.	15.8 lbs.	No. 16	11.25 lbs	81 lbs.
16	⅜ " "	2.9 "	11.9 "	" 16	14.5 "	61 "
20	½ " "	6.0 "	16.2 "	" 16	18 "	49 "
24	½ " "	7.3 "	13.5 "	" 14	27.25 "	52 "
30	½ " "	8.6 "	10.9 "	" 12	44 "	54 "
36	½ " "	9.9 "	9.0 "	" 11	58 "	50 "
42	½ " "	11.1 "	7.7 "	" 10	74.5 "	48 "
48	½ " "	12.2 "	6.8 "	" 10	85 "	42 "
54	⅝ " Upset	23.6 "	13.2 "	" 10	95 "	33 "

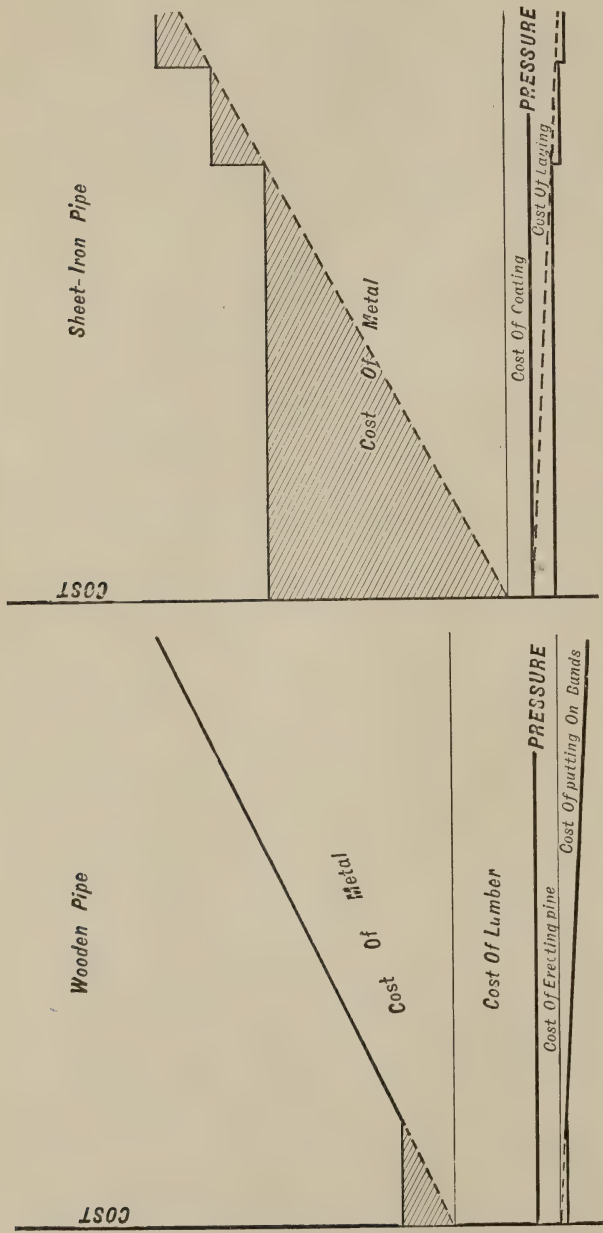

FIG. 3.

COMPARATIVE COST OF WOODEN AND SHEET-IRON WATER PIPE FOR VARYING PRESSURES.

The gauge of the sheet iron has been assumed as light as only the most favorable circumstance will allow, and the weights are based on straight pipe, with slip joints, and exclusive of the weight of the coating.

Beside the mere comparative weight of metal there enters a factor of comparative cost per pound. It is true that the actual cost of working sheet iron may be brought down to a low figure, but it requires expensive machinery, working only part of the time, and depreciating all the time. For the manufacture of bolts, such as are used on wooden pipe, no special machinery is required, bolts being a

FIG. 4. 37-INCH PIPE AT DENVER, COL.

staple article in the market. And the tools needed for erecting the wooden pipes are few, simple and cheap. It must also be remembered that the comparison of cost should take into account the comparative carrying capacity, which, where prices seem equal, makes wooden pipe between 5 and 10 per cent. cheaper per gallon of water carried than sheet iron.

FIG. 5. 14-INCH PIPE AT PROVO CITY, UTAH.

As it bears on this subject, I wish to quote from a report made about a year and a half ago to the Pueblo Gravity Water Co., by one of our members, Mr. James D. Schuyler.

"I have recommended the use of 5,630 feet of 30-inch, and the remainder, 70,140 feet of 24-inch pipe, to be made of California redwood staves, built continuously in the trench and banded with round steel bands. This recommendation has been made for the following reasons:

First.—After thoroughly investigating the history of wooden pipe as laid for seven years past in Colorado, and after examining a number of lines in use, I have come to the conclusion that if the bands are properly coated and the pipe kept full of water it is practically indestructible, and certainly has a longer life than sheet iron or steel riveted pipe.

Second.—The interest on the *difference* in cost between wood and cast iron pipe of the same capacity will replace the wood pipe every ten years, which I think is but a fraction of the life of wood pipe, and therefore it would be a prodigal waste of money to put the amount of capital necessary to lay cast iron mains into the enterprise.

Third.—The wood pipe is cleaner, does not become foul, does not rust, does not fill with tubercles that diminish the capacity year by year, has no yarn to rot and contaminate the water, will not break by settlement, will not burst so readily under water hammer, and so long as it lasts is, in every respect, cleaner and more desirable.

California redwood is so much better adapted to that purpose than any other wood available, that I recommend that material."

For the 16 miles of 30-inch wooden pipe, built by the Citizens Water Co., of Denver, two years ago, the comparative figures of cost, roughly stated, are about as follows:

Actual cost, wooden pipe	$160,000
Estimated cost, riveted iron pipe	333,000
Estimated cost cast-iron pipe	717,000

This line of pipe is almost entirely under a pressure varying from 50 to 220 feet. It was built of Texas pine. If redwood had been used, as it will be for all new pipe lines now contemplated by this company, the cost of the wooden pipe would have been about $185,000.

PIPE LINES IN USE.

Besides a number of short irrigation siphons in Colorado and New Mexico, varying in diameter from 24 to 72 inches, there have been built, during the last eight years, the following pipe lines, arranged in chronological order:

3.2	miles	48	inch	pipe	Denver Water Co.
5.75	"	37	"	"	" " "
1.	"	30	"	"	" " "
1.25	"	24	"	"	" " "
3.	"	12	"	"	" " "
2.	"	25	"	"	" " "
0.5	"	48	"	"	City Ditch, Denver.
0.75	"	30	"	"	Cheyenne Water Works.
1.78	"	24	"	"	" " "
1.13	"	24	"	"	Irrigation purposes near Denver.
3.	"	12	"	"	East Denver.
0.8	"	54	"	"	Irriga'n siphon, Bessemer Ditch, n'r Pueblo, Col.
5.	"	24	"	"	Ogden (Utah) Water Works.
16.	"	30	"	"	Citizens Water Co., Denver.
3.13	"	12	"	"	Aurora Water Works, near Denver.
6.5	"	30–18	"	"	Perris Water District, Cal.
3.75	"	14	"	"	Provo City (Utah) Water Works.

The pipe lines at Cheyenne were constructed in a poor manner and of cheap material, and have not given satisfaction.

Note.—The pipe built for the Perris Water District is slightly different from the other pipes mentioned, in that it has the edge of the staves dressed in a V shape, instead of flat.

CONCLUSION.

Before a body of engineers it is unnecessary to state to what purposes this pipe is adapted. Yet I wish to call your special attention to its comparative cheapness under light heads. Long gravity mains for domestic supply can often be located so as to keep the pipe close to the hydraulic grade line. It offers advantages, regardless of its cost, which commend it particularly to irrigation engineers. And that it is applicable to the development of water power and to hydraulic mining will be readily understood.

DISCUSSION.

Prof. Keith.—The paper read this evening recalls to my mind that in 1863 I had occasion to build a species of wooden pipe for carrying water through a mill building on Clear Creek, near Black Hawk, Colorado. The building stood on a side hill, and before the pipe was used the seepage from the ditch, which was first used to convey the water, was a source of annoyance. The pipe was built with tapering ends, so that one length fitted into the mouth of the next length of pipe. The bands were made to different sizes, and driven on to the pipe to sustain it. This pipe though

a somewhat crude device answered our purpose excellently, did not leak at all, and was in use for the four or five years I was there, and may be so still."

PROF. SOULÉ—"What care is taken to place bands over the joints where the iron plates are inserted?"

MR. HENNY.—"The pipe is built, more or less, in sections, and at places where the joints come we usually put one extra band, but we do not pay any attention to the bands being placed right over the joint."

MR. ALLARDT.—"How do you manage where pipe lines branch or cross?"

MR. HENNY.—"Cast iron specials are used with large and deep bells. The wooden pipe enters the bell, and the space between the pipe and the bell is caulked with oakum or with lead."

Q.—"How long do you make the staves?"

A.—"All the way from 12 to 20 feet."

Q.—"Is it necessary to have special machinery for making staves?"

A.—"We have special machinery for cutting staves for tanks; all that is required besides is machinery for slotting the ends."

PROF. SOULÉ.—"Did I understand you to say the pipes remain perfectly clean and free from vegetable growth or fungi?"

A.—"Yes. Most vegetation in the water requires light, and of course that is excluded."

Q.—"Have you ever noticed any special eroding or working away of the wood after pipes have been in use?"

A.—"Our experience with this stave pipe is not long enough to say. I have heard of 4-inch bored, log pipe that when taken up measured 5 inches. I suppose, however, that such wearing away takes a long time, a high velocity of the water, and presumably grit or sand in the water."

Q.—"Do you put any preparation on the wood, inside or outside, to preserve it?"

A.—"No sir."

Q.—"Do you prefer seasoned wood?"

A.—"Yes, in all cases, to prevent shrinkage after it is milled. Most of the wood is kiln dried."

Q.—"The best form of stave, after all, is the straight edge, is it?"

A.—"That is my opinion. We have never had any trouble with the seam joints, except where one could distinctly see some

defect in the stave, but experience has shown that the pipe must be carefully built to be thoroughly tight."

Q.— "What is the smallest size of pipe made of staves?"

A.— "The smallest size is 12 inch. I am now building at the works some 6-inch pipe. I have used staves out of one-inch lumber reduced as low as half an inch in thickness at the joints, and it makes a very stiff pipe."

Q.— "I suppose from that size up you can build as large as is required for practical purposes?"

A.— "A seventy-two inch pipe line built on the Maxwell Grant is the largest constructed so far, but there is no difficulty in building larger diameters if required."

MR. ALLARDT.— "Has any of this pipe been used for sewer purposes?"

A.—"Not as far as I know."

Q. "In a general way how does the cost, including the very large pipe, compare with the cost of sheet iron, or sheet steel?"

A.— "The cost of this pipe is dependent upon the pressure. Ten feet pipe, built of 4-inch lumber, banded with ⅞ steel bands 12 inches apart, is listed, including laying, at $13 a foot. Twelve-inch pipe with bands every foot at 80 cents, laid. The freight, if the pipe were to be used some distance from San Francisco, would be added, that is, on the lumber. For Eastern points this would be partly balanced by a saving on freight on the bands. The bands are sent direct from the factory to the place of destination, so the wood from San Francisco and the iron from the East meet at the work for the first time."

Q.— "Is it well determined that the wood does not rot on the outside of the pipe?"

A.— "Mr. Hull, an engineer in Connecticut, having built a good deal of this pipe, writes, after 40 years of experience with wooden pipe, that if the pipe is laid above ground and kept full of water its life would be about forty years, but if laid underground and covered over he considers its life indefinite, there being no rot to it."

PROF. SOULÉ.— "I have a piece of bored log pipe which was buried in the ground for 15 years, and used for carrying water for domestic purposes. You can scratch the outside anywhere, and the redwood is perfectly sound. The bore I think is two inches, and the log is about 4 inches square. I mention it simply to show the durability of the wood. It was not decayed in the least. I think, in this case, the wood, while the pipe was in use, was completely saturated with water."

Q.— "How are the bands protected?"

A.— "They are coated with paint or asphaltum. In case the bands should rust off in the course of years, new bands could be put on between the old ones, and the staves saved."

Q.— "Have you had experience with these pipes when laid on the surface of the ground?"

A.— "No sir, in Colorado these pipes are laid underground to avoid freezing of the water in cold weather."

Q.— "Is the wood surfaced on both sides?"

A.— "Yes sir."

Q.— "How much does the mill charge per thousand feet, board measure?"

A.— "Thirty-three dollars."

Mr. Vischer.— "I would like to ask Mr. Henny whether he has ever examined wooden pipe carrying water, to determine to what depth the wood was saturated with water?"

A.— "I have examined pipe with 1⅜ inch of shell, under nearly all pressures up to 165 feet, have cut into the pipe and found the wood looked damp, but did not show any signs of water oozing out."

Mr. Vischer. — "This pipe would, I think, derive certain advantages from the smoothness of its inner surface, in a capacity to withstand freezing of the water carried by it, when exposed to great cold. This is often a serious drawback to the use of iron pipe in cold climates, especially where supervision of the line is difficult. Freezing of the water is generally not directly brought about by the water being frozen at the point where stoppage takes place, but by the lodging of "scum" or "float" ice against surface obstructions in the pipe, which form initial points from which, by subsequent accretion, the whole area becomes closed. My experience was with iron pipes not larger than 8 inches diameter, and larger pipes, probably, are less liable to stoppage by freezing. However, the smooth and uniform inner surface should be an advantage, besides the greater thickness of the wooden shell of itself aiding in resisting cold. I think wooden pipes might be laid at less depth than iron, which advantage is often material when frozen pipe lines have to be hurriedly uncovered.

The correct thing is, of course, to put the pipes deep enough in the ground from the first, so that freezing will not take place, but this is not always easy to accomplish. Merely laying pipes below the frost line is not a guarantee against their becoming frozen.

In case of freezing, the remedy usually is, after locating the frozen section and uncovering the pipe, to build fires under it, by which process pipe is often burned and the iron much injured wherever the stoppage, instead of being continuous, consists of patches of ice, with empty spaces between them. Pipe which has been so heated several times, has its life pretty well exhausted. If the stave pipe should become stopped by freezing, it seems to present facilities for opening up a section by loosening the bands and removing the obstruction without damaging the pipe."

MR. HENNY.—"Mr. Vischer is right, I think. In Utah, we covered this pipe with two feet of dirt, and the cast iron we covered three and a half feet. So far we have not had any stoppages from freezing. I built a main line of 12-inch cast iron in South Dakota, and covered it seven feet. In the Northern Peninsula of Michigan we covered the pipes seven feet and over, and I heard after I left they had considerable trouble with freezing of the mains. In Denver the mains are covered about four feet; in Leadville, eight and one half feet."

MR. ALLARDT.—"There is a royalty on the pipe, is there not?"

A.—"Yes, but it is merely nominal. Mr. Allen, who had the patent, has given us the right for this part of California and for the Western States."

Q.—"In building a line of pipe, how much care do you have to take in laying it to exact grade before tightening the bands and filling the trench?"

A.—"The pipe is laid to the trench as graded, and the bands then tightened. We do not dig the trench wider than we can help, and we aim to have an equal space on each side of the pipe to work in."

PROF. KEITH.—"How about expansion?"

A.—"I have always laid this pipe in a trench, and have taken pains to have it back-filled immediately after construction, so that there would not be great changes in the temperature of the pipe. Where the pipe had been exposed I have never noticed any expansion. As regards expansion caused by saturation, the swelling of the wood lengthwise causes the butt joints to become perfectly tight."

Q.—"Have you ever had trouble from animals and rodents knawing the pipe in pursuit of water in a dry country?"

A.—"I have never known any trouble from this source."

PROF. CARNOT.—"It gives me extreme pleasure to be with you tonight. I am very glad to have had one opportunity during my trip through America of seeing some society of this kind, and the tone and scope of the discussion of its papers. I must say I have been very highly gratified. The subject is entirely a new one to me. It appears to have been handled in a very able and thorough manner, and there is much food for reflection. I would have liked, however, to have had a few more figures in regard to prices for comparison of its cost with that of other kinds of pipe.

As far as I am aware, we have no wooden pipes in Australia. Up to a few years ago we used cast-iron pipes, then an innovation came in the way of wrought iron, and that is now extensively used. During the past five or six years there is an entire cessation almost of the use of cast-iron pipes. In Melbourne we have works where machinery is used for manufacturing wrought-iron pipe, and it is turned out in large quantities. One point of interest to me, and one I have never been able to get any satisfactory information upon, namely, as to how far the lap of the plates and the heads of the rivets impede the flow of the water.

This timber pipe is quite a novelty to me, and the idea of making a large water main out of timber comes to me certainly in the light of a revelation. The question that suggests itself to my mind, of course, is how far is it applicable to the conditions that exist in Australia? We have a very small supply of pine wood; all our wood, as a rule, is very hard indeed, and intensely hard after it is seasoned. Here, as I understand, you have a pipe which is cheaper than either cast or wrought iron, which, as far as can be seen, is equally durable—at any rate, quite as durable as wrought iron—for I presume, the bands could be protected as well as the iron of wrought iron pipes could be protected. We are told, that as far as seen, when underground it is cleaner and smoother than cast-iron pipe, and, of course, much more so than the wrought iron. It certainly seems as if it were a great improvement, and was likely to be of very great value indeed. Knowing nothing about the subject practically, myself, I cannot add anything further, except to say that I feel very pleased indeed with the paper, and also with the discussion. It seems to me that it is a very marked advance in connection with water supply matters.

Of course the question of how it would do for sewerage is of still further interest. We are about to expend several millions of dollars

upon sewerage works in Melbourne. It would be interesting to know if pipe of this description would answer the purpose.

There is another pipe I would like to put in comparison with it, and that is the earthenware pipe. It is comparatively cheap; it is very smooth and cleanly, but will not stand a very great pressure. We have used it to some extent for carrying water supplies, and with some success. But for sewerage purposes it is universally used. Perhaps the use of wooden pipe for sewerage purposes is a little remote.

I thank you for this opportunity of addressing the meeting; I only regret that my departure for Australia on the steamer tomorrow will prevent my meeting with the members and becoming personally acquainted with them."

Q.—"Is not the use of earthenware pipe naturally a restricted one for water supplies, on account of the inability of the joints to withstand 'water hammer'?"

PROF. CARNOT.—"Of course we only use it under circumstances where 'water hammer' can be guarded against. I have known, however, of earthenware pipe being used with success in conducting water for small towns, for instance where water has been taken from an aqueduct, a distance of several miles to a surface reservoir, metal pipes being used to conduct the water from the reservoir to the town."

MR. VISCHER.—"While not strictly pertinent to the subject of wooden pipe, I would like to ask if any member is able to express an opinion as to the relative merits of steel and wrought iron as regards durability. Perhaps Mr. Dickie has some data upon this subject?"

MR. DICKIE.—"I think durability would be in favor of the iron; it would depend, however, mainly upon the coating. When the coating is gone the life of the pipe is very short, as we all know in handling pipe.

I have listened very attentively to this subject tonight, but there is one thing I must say I cannot understand. In this wooden pipe it is not claimed that the wood presents any resistance to the pressure; therefore it is no factor whatever in the strength of the pipe. If the wood is banded by steel, there must necessarily be as much steel in the bands as would make a steel pipe of the same strength. Now, steel formed into bands with a head on one end of the band and a nut on the other will certainly cost as much as manufactured steel pipe. Under these circumstances I do not see how the wooden

pipe can be made cheaper. I am talking about a pipe under pressure. The thickness of the metal is dependent upon the pressure it has to stand. Now I take it that the bands of a wooden pipe, under a head of 200 feet, would cost as much as a steel pipe carrying the same head. I think the cost of manufacturing steel into pipes in San Francisco is not more than seven eighths of a cent per pound, and that would be the amount that you would have for manufacturing the bands and making them ready for use in supporting the wooden pipe. The thread cut in the band takes out about the same amount as is taken out of a double-riveted iron pipe, so that the amount of material would be absolutely the same. I am not clear about the relative cost of pipe as represented by Mr. Henny's diagram; the difference, however, appears to me too much. As regards the steps shown in the diagram, when material is ordered for pipe at the mills, the increase of the thickness of the pipe is a very small factor. I know of instances where the variation in thickness of metal is very small indeed as pressure increases. I think this can be regulated as closely as the spaces between the bands of wooden pipe."

Mr. Henny.—"In answer to Prof. Carnot's remarks regarding exact figures as to the cost of this pipe, I can give list prices, quoted by the Excelsior Redwood Co. They are for pipe, banded every 12 inches and include cost of erection:

12 inches	80 cents	36 inches	$2.05	72 inches	$ 5.60
16 "	$1.00	42 "	2.35	84 "	7.25
20 "	1.30	48 "	2.65	96 "	9.60
24 "	1.50	54 "	4.35	108 "	10.80
30 "	1.75	60 "	4.80	120 "	13.10

Professor Carnot thinks that wooden pipe is about as durable as wrought iron pipe, but it appears to me reasonable to suppose that its life is much longer. As Mr. Dickie remarks, when the coating is gone the life of sheet iron pipe is very short. This holds good for those parts of the pipe where the coating has been knocked off, or is cracked, or is imperfect. For, under ordinary methods of pipe laying, who can guarantee absolutely perfect coating after the pipe is laid? Now the slightest imperfection in the coating leaves but from $\frac{1}{20}$ to $\frac{1}{12}$ of an inch of short-lived material to rust away, in order to have a leak. If one could keep sheet iron pipe tight, notwithstanding its rusting through in spots, until enough metal is worn away to make the pipe burst, then its life would approach that of wooden pipe. On the grade line, I agree with Professor Carnot that vitrified

sewer pipe is to be preferred to wood. But, I think, the largest size manufactured is 30 inch, and at that size it becomes very expensive. Then it must be kept to the exact grade line, as the cement joints cannot be depended upon under even slight pressure.

In comparing the diagrams of cost, Mr. Dickie appears to misunderstand me, as I do not claim that under high pressures wooden pipe is cheaper than sheet iron pipe. I believe to have called your attention this evening to the fact that no matter what material is used for the shell, the same amount of metal is required in either case to resist the bursting strain. What I attempted to show in the diagram is that, over and above this amount, there is required considerable metal in the case of sheet iron pipe under low pressure, simply to make the pipe stand up under outside pressures. It is under light heads that wooden pipe has the advantage of cost over sheet iron pipe, but it has the advantage of durability under all pressures."

Mr. Vischer.—"The longitudinal stiffness of the wooden lining should make the pipe self sustaining for certain lengths when carrying water, thus making it available for support on trestles if desirable. This may not often become necessary, yet I have known a case in the Sandwich Islands where this quality, if it exists to any extent, would have been highly in its favor. A swamp, with rock bottom, was overlaid by oozy, almost fluid mud, two to four feet deep. Trenches could not have been dug, and by far the simplest method would be to lay the whole pipe on low horses above the mud surface. Here all the material would have had to be packed on the men's backs for several miles, and the extreme lightness of the parts of which the stave pipe is built would have greatly recommended it. In fact, this quality should not be under rated, for lightness of parts is often more essential, where transportation is difficult, than lightness per foot of finished pipe."

REGULAR MEETING, MARCH 4th, 1892.

PROCEEDINGS.

MINUTES.

The meeting was called to order by the President, John Richards.

The minutes of the last regular meeting were read and approved.

The following new members, having been balloted for, were declared elected:

Conrad Eimbeck, Civil Engineer.....Guaymas, Mexico.
D. C. Henny, Civil Engineer.....San Francisco, Cal.
Alex. M. Reynolds, Civil Engineer.....Seattle, Wash.
Arthur H. Sanborn, Ass't City Surveyor.....San Francisco, Cal.

The following names were proposed for membership and referred to the Board of Directors:

Andrew Fraser, Mechanical Engineer, of San Francisco; proposed by John Richards, H. C. Behr and F. Orton.

Edward C. Jones, Civil Engineer, of San Francisco; proposed by Jos. B. Crockett, A. Schierholz and H. C. Tabrett.

Chas. D. Marx, Professor of Civil Engineering, Leland Stanford, Jr., University, Palo Alto; proposed by Horace B. Gale, Frank Soulé and C. E. Grunsky.

Leon H. Taylor, Civil Engineer, of Long Valley, Cal.; proposed by Wm. Minto, C. E. Grunsky and Otto von Geldern.

The Secretary read the following communication from the President:

A COMMUNICATION.

To the Technical Society of the Pacific Coast:

Having received the following communication from our distinguished Past President, Col. George H. Mendell, Engineer Corps, U. S. Army, I feel it incumbent on me to present it here with Colonel Mendell's consent, and in accordance with the suggestion it contains, to offer such personal explanation as the circumstances call for.

Colonel Mendell's communication is as follows:

"MR. JOHN RICHARDS,
President of the Technical Society, San Francisco, Cal.

SIR:—In the annual address to the Society of which you are President, read on January 15, 1892, the following remarks occur:

"'The improvement of rivers and harbors by the general government I think had better not be mentioned. So far as this Coast is concerned there seems no complaint, but on the Atlantic side the record is not one to call for commendation, when compared with the achievements of private enterprise.'"

My acquaintance with the improvements of rivers and harbors on the Pacific Coast permits me to say that there is no reason, relating to the works themselves, why they may not properly be mentioned and discussed. The engineers responsible for the works not only can have no objection, but would doubtless favor thorough discussion.

My acquaintance with works of this character on the East of the Rocky Mountains is less close. I know, however, many of the engineers who have now, or have had charge of these engineering works to be men of character and ability.

The opinion which you express, to the effect that these works are not worthy of commendation, is not the one generally held, and is, I am assured, a mistaken view. If it were otherwise, the direction of these works would long since have passed into other hands. But you appear to have reached your conclusion after study, implied by your references to a record.

You may be in possession of information not generally known. The subject is one of general interest, and of great importance. The reputation of a worthy class of men is assailed by your statement.

You will therefore doubtless perceive the propriety, upon request now made, of laying before the Technical Society, or otherwise making public, the facts which, in your opinion, justify the disparaging assertions and implications contained in the quoted statement.

Very respectfully,

(Signed.) G. W. MENDELL."

In respect to this communication, and the subject incidentally referred to in the address, the works in question are matters of national and general concern, and involve features quite distinct from and independent of the ability of the Engineer Corps, which it was not the intention to call in question at the time of writing the sentence quoted from the annual address.

The words used hardly call for this disclaimer of any intention to reflect upon the personelle or qualifications of the Engineer Corps. If so, full apology is now made, but as before said, the works are of public concern, subject not only to the criticism common to all such undertakings, but in greater degree, because executed outside of what may be called the profession in general.

My impression cannot therefore be considered as carrying other weight than that of personal opinion, and as such, liable to error; especially as in this case the subject pertains to a branch of engineering work with which I am not familiar.

There was in the use of that term "record," no intention of declaring information, except in a limited degree, other than is open to everyone in the technical and secular literature of the time; in this sense the term record was employed.

It must be admitted, even by the Engineer Corps and their friends, that serious criticisms of many of the river and harbor works on the Atlantic side of the country have appeared recently in journals of good, or even high standing, and at times over the signature of civil engineers of wide repute.

I do not think it necessary or expedient to cite references generally accessible in current technical literature, or to seek support for my statement in such expressions as those contained in a recent report to the St. Paul Chamber of Commerce by a committee of theirs, on the works carried out on the Upper Mississippi River.

Such presentations here would perhaps lead to a spirit of controversy, undesirable and unnecessary if Colonel Mendell will admit that such published matter was sufficient to call out the expression used in respect to government engineering works on the Atlantic side of the country, especially as at the time of writing no reply had been made to some of the most serious of the charges presented.

I think it due to Colonel Mendell to say that since receiving his communication, some inquiry among the profession here develops the fact that his own administration on the Pacific Coast has not only escaped criticism among the profession generally, but earned both approbation and admiration.

As even errors and mistakes can have a useful side, so it may be in this case, if the criticisms of public works will bring to the notice of this Society, the points in controversy between the private and government engineers in the East, especially if such consideration will induce Colonel Mendell and his staff to lay before the Society information respecting works under his administration, which will have an especial interest to the members.

February 22d, 1892.

Since the preparation of the foregoing communication I have received from Colonel George H. Mendell documentary evidence of both a public and private nature, showing beyond mistake that not only have the works in the upper Mississippi been beneficial, but that such works have met with commendation from all but a few sources among those interested.

The papers submitted by Colonel Mendell are:

(1) A communication from Major A. Mackenzie, in charge of the Government work on the Upper Mississippi River.

(2) Communications to Major Mackenzie from some of the principal steamboat lines, accompanied in some cases by records and dates of a character to show an improvement of the channels, and commendatory of the works carried out under the Corps.

(3) Private letters by shipping firms, asserting that the works under Major Mackenzie's administration, have been of great benefit to the interests of navigation.

(4) A communication from C. C. Andrews, Chairman of the Committee on the Mississippi River, St. Paul Chamber of Commerce, stating that the resolution passed by the chamber on Dec. 10th, 1888 was a mistake in so far as being a concensus of opinion in that body, having been withdrawn or rescinded by a subsequent resolution passed on the 17th of December succeeding; also saying, that the Government Engineer Officers enjoy fully the confidence of that Chamber.

(5) Quotations from the Editorial Columns of the "St. Paul *Pioneer Press*," of Dec. 12th, 1888, condemning and denying the allegations set up in the resolution passed by the Chamber of Commerce on Dec. 10th, 1888.

The copious nature of the public portion of these various documents prevents them being presented here, and it is not necessary, as

Colonel Mendell indicates, further than to, on my part, concede the error of the statement at first quoted from my annual address.

My information respecting the Government engineering works on the upper Mississippi was mainly of an *ex parte* nature, derived from private sources and from newspaper clippings with dates removed, but left to inference as being current.

I think that the substance of these remarks, spread upon the minutes of the Society, will very fully eliminate any effect produced by the remarks in the annual address.

As the editor of a publication dealing to some extent with engineering matters, perhaps my opportunities for observing the untruth and unreliability of floating news is greater than most members of the Society, and I take this occasion to say that the untrue and inexact part is the main one.

San Francisco, March 4, 1892. J. RICHARDS.

Dr. R. Heidrich then addressed the members on the subject of Mnemonics, and its usefulness in mentally retaining data and formulæ. Examples were given to show the simplicity of impressing the mind with a subject, connecting this with any other fixed in the mind, and calling up that subject, thereby, at any time. Dr. Heidrich had committed to memory the first fifty logarithms to seven places of decimals, and repeated them at the pleasure of the members to any desired natural number.

The interesting subject was discussed, after which a vote of thanks was passed for the author. (The paper will be published in a subsequent bulletin.)

The Nicaragua Canal Committee having been requested to make a report in the near future, the Chairman of that committee announced that one would be submitted at the next regular meeting.

Adjourned. OTTO VON GELDERN, *Secretary.*

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